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COST AND EFFECTIVENESS EVALUATION OF AUTOMATED CARGO DELIVERY SYSTEMS IN ARMY AIRCRAFT

By

Donald A. Andrastek
Reginald R. Belding
James W. Wollaston

June 1966

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

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The possibility of improving the efficiency of the delivery function of Army transport aircraft by the addition of partially automated, internal cargo handling equipment provides the basis for this investigation. The contractor has developed a responsive cost/effectiveness technique of analysis which, when tempered with qualitative considerations, is capable of establishing the degree of automation that is warranted. The contractor has furthermore demonstrated that specific aircraft performing certain typical missions can achieve increased effectiveness at decreased cost by the addition of relatively unsophisticated cargo handling equipment.

This command concurs in the analytical techniques developed and the conclusions drawn. A detailed design study, which should be integrated as early as possible into the design phases for future transport aircraft, remains essential prior to the selection of specific cargo handling equipment. The developed analytical technique represents a significant contribution to assist in a study of this type.

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Final Report

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by

Donald A. Andrastek
Reginald R. Belding
James W. Wollaston

Prepared by

Douglas Aircraft Company, Inc.
Aircraft Division
Long Beach, California

for

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

ABSTRACT

In the first phase of the two-phase study, methodologies were developed to (1) measure the degree of automation of a given cargo handling system and (2) evaluate the gains and penalties resulting from automating cargo handling functions in Army aircraft from a cost/effectiveness point of view. Basic to the study were the effects of cargo handling equipment in Army aircraft on aircraft payload, cargo handling time, manning, aircraft availability, aircraft vulnerability and costs.

Several cargo handling systems were evaluated in the second phase of the study. These systems ranged from manual to very highly automated and were evaluated in the CV-2, CV-7, CH-47, and a hypothetical 10-ton STOL. Elements not affected by the cargo handling system were held constant whenever possible.

FOREWORD

This report was prepared by the Aircraft Division of Douglas Aircraft Company, Inc., Long Beach, California, and represents the results of a 1-man-year study conducted under Contract DA 44-177-AMC-270(T).

The study was initiated 10 May 1965 and completed 11 October 1965. Phase I of the study effort terminated 10 August with the submission for approval of the analytical method developed during the preceding 3 months. Following approval of the Phase I methodology, cost and effectiveness data were developed and several Army aircraft were evaluated in Phase II of the study.

Lt. J. A. Deacon of the U. S. Army Aviation Materiel Laboratories (USAAVLABS) was the project officer. Mr. J. W. Wollaston, of the Douglas Aircraft Company, Inc., was the technical director responsible for the study. Mr. D. A. Andrastek, Systems Cost Analyst, was responsible for the cost methodology and evaluation. Cargo handling data development was under the direction of Mr. R. R. Belding, engineer specialist, assisted by W. T. Bell, A. Miller, D. A. Eidsmore, T. W. Miner, and A. I. Curry, all of the Support Equipment Section. Mrs. S. A. Haskins of the Douglas Computing Services Group was responsible for the computer programming required.

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LIST OF SYMBOLS

A_I	Number of operating (flyable) aircraft required to perform a stated mission with due allowance for aircraft downed by accidents or by enemy fire.
A_{IY}	That portion of A_I attributable to the transport of cargo type Y.
A_L	Number of aircraft downed by accidents and enemy fire in the performance of a stated mission.
A_{LY}	That portion of A_L attributable to the transport of cargo type Y.
A_P	Number of aircraft required to perform a stated mission, including unavailable aircraft.
A_{PY}	That portion of A_P attributable to the transport of cargo type Y.
CHS	Cargo handling system.
C_{LYN}	Quantity of cargo of load type N, cargo type Y in a single aircraft load (tons).
C_{TYN}	Total quantity of cargo of load type N, cargo type Y (tons).
C_T	Total quantity of all types of cargo (tons).
C_{TY}	Total quantity of cargo type Y (tons).
F	Fraction of the aircraft downed by accidents and enemy fire that are a total loss.
I	Automation index for total composite cargo quantity.
I_D	Total investment cost to replace one lost aircraft and its cargo handling system ($).
I_{ODA}	Amortized aircraft investment cost per operating day, comprised of the unit flyaway cost and unit initial support cost of each aircraft ($).
I_{ODC}	Amortized cargo handling system investment cost per operating day, comprised of a unit research and development cost (if any), unit flyaway cost, and initial support cost ($).
I_T	Total investment cost allocated to a stated mission (aircraft and cargo handling system) ($).

I_{TY}	That portion of I_T attributable to the transport of cargo type Y ($).
I_Y	Automation index for cargo type Y.
K	Delivery mode factor (K = 1 for airdrop and K = 0 for airland).
L_T	Replacement cost of lost aircraft, i.e., downed during mission and not repairable ($).
L_{TY}	That portion of L_T attributable to the transport of cargo type Y ($).
M	Cost to perform a stated mission, including amortized investment cost, operating cost, and loss cost ($).
M_Y	That portion of M attributable to the transport of cargo type Y ($).
N	Code for type load of cargo type Y.
O_{FH}	Operating cost per aircraft per flight hour, including POL cost per flight hour and aircraft recurring parts cost per flight hour ($).
O_{GH}	Operating cost per ground hour, including CHS recurring parts cost, load/unloading labor cost and ground handling equipment cost all amortized per unit of ground-hour operation ($).
O_{OD}	Daily operating cost per aircraft, including daily flight crew cost, daily aircraft maintenance crew cost, and daily CHS maintenance crew cost ($).
O_T	Total mission operating cost ($O_{FH} + O_{GH} + O_{OD} + O_{TL}$) ($).
O_{TL}	Operating cost per ton loaded, including the cost of labor and material expended in the special cargo preparation required by some cargo handling systems ($).
O_{TY}	That portion of O_{TL} attributable to the transport of cargo type Y ($).
P	Inverse of delivery system (aircraft + CHS) availability expressed as a fraction greater than one.
S	Cargo handling system code number.

T_F Cumulative flight time for A_{IY} or A_I aircraft in time T_T (hours).

T_{FY} That portion of T_F attributable to the transport of cargo type Y.

T_{OD} Length of operating day (hours).

T_T Total time to complete deliveries measured in operating-day hours (T_{OD} number of days available to perform the mission) (hours).

T_1 Loading time for load type N in one aircraft (primary flight) (min).

T_2 Tiedown time for load type N in one aircraft (primary flight) (min).

T_3 Weight and balance time for load type N in one aircraft (primary flight) (min).

T_4 Time to taxi, takeoff, and climb to cruise altitude (primary flight) (min).

T_5 Flying time in transit (primary flight) (min).

T_6 Time to approach and land (primary flight) (min).

T_7 Time to release restraint for load type N in one aircraft (primary flight) (min).

T_8 Unload time for load type N in one aircraft (primary flight) (min).

T_9 Loading time for load type N in one aircraft (retrograde flight) (min).

T_{10} Tiedown time for load type N in one aircraft (retrograde flight) (min).

T_{11} Weight and balance time for load type N in one aircraft (retrograde flight) (min).

T_{12} Time to taxi and takeoff (retrograde flight) (min).

T_{13} Flying time in transit (retrograde flight) (min).

T_{14} Time to approach and land (retrograde flight) (min).

T_{15}	Time to release restraint for load type N in one aircraft (retrograde flight) (min).
T_{16}	Unload time for load type N in one aircraft (retrograde flight) (min).
T_{17}	Refueling time allocated per cycle per aircraft (min).
V_1	Aircraft downed by accidents per single aircraft per cycle.
V_2	Aircraft downed by enemy fire per single aircraft per cycle.
Y	Pure or mixed cargo type code number.

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SUMMARY

INTRODUCTION

The Army has a growing organic air transport capability, both fixed and rotary wing. Operational requirements and monetary limitations cause a pressing need for the Army to obtain the highest efficiency in the delivery capabilities of present and future Army aircraft.

The purposes of this study are to develop means of measuring automation per se and the gains and penalties resulting from automating cargo handling functions in Army aircraft and then to define the approximate degree of cargo handling system automation desirable in Army aircraft.

In this context, automation is defined as the reduction of human energy input or human decision in a cargo handling operation or task by the addition of equipment to an aircraft.

There are two primary effects of automating cargo handling functions in Army aircraft:

1. Cargo handling time savings.
2. Payload degradation due to the weight of the cargo handling equipment.

Current Army aircraft reflect the nature of the Army missions: they are designed to carry small payloads over short distances and to operate from forward area facilities. Since the mission radii are short, especially for helicopters, cargo handling time is a significant part of total cycle time, and savings in cargo handling time are significant. As the payloads transported are small, the degradation of the available aircraft payload due to the weight of equipment added to the aircraft is likewise significant.

ANALYTICAL TECHNIQUES

The object of Phase I of this study was to develop an overall cost/effectiveness methodology for analyzing the gains and penalties resulting from automating cargo handling inside Army aircraft.

During Phase I, four separate (but interrelated) methodologies were developed to measure

1. The degree of automation represented by any given cargo handling system (automation index).
2. The effectiveness resulting from a particular cargo handling system having a given degree of automation.

3. The costs associated with a particular cargo handling system.

4. The resultant cost/effectiveness of a particular degree of automation and the general degree of automation desirable in Army aircraft.

Automation Index

The automation index concept is a normalized measure of the degree of automation inherent in a particular cargo handling system, against which to relate the cost, effectiveness, and cost/effectiveness measures of that system. The actual calculations of cost and effectiveness do not, however, in any way depend on the automation index value. A cargo handling system may be evaluated for a specific mission without using any automation index.

The amount or degree of automation present in a cargo handling system is difficult to measure. The functional evaluation method adopted rates the degree of automation of each function involved in the cargo handling process from 0 (manual) to 6 (fully automated), then sums the rating values for all of the functions to obtain an automation index value for the cargo handling system. Weight and balance computation was not included in the automation measure because the weight and balance system is independent of the cargo handling system.

Effectiveness

The primary quantitative measure of effectiveness in this study is the number of aircraft required to fulfill a fixed mission requirement; namely, the delivery of a defined cargo quantity in a given number of 12-hour operating days.

In addition to handling time savings and payload degradation, some cargo handling systems affect aircraft availability, vulnerability, operating manpower, and maintenance men and materials. The effects of these factors counteract, but do not necessarily counterbalance, each other.

A number of other factors affect the evaluation, but serve only as an evaluation framework. These framework factors may be classed as mission parameters, aircraft parameters, and cargo parameters.

As the object of the study is to evaluate the automation of cargo handling inside Army aircraft, those factors not determined by the degree of automation of the cargo handling system (e.g., aircraft model, cargo, environment, and weight and balance system) are held constant whenever possible.

A number of effectiveness factors do not lend themselves to quantitative analysis and must be viewed qualitatively. This in no way implies that these qualitative factors are unimportant.

Cost

A total mission cost method was selected as the best cost approach for evaluating the various configurations of automated delivery systems. Total mission cost is defined as the cost associated with meeting a fixed mission requirement; i.e., the delivery of a fixed quantity of cargo in a fixed time period.

Any cost calculation for an n-year period is not applicable because neither the entire array of missions performed over the life of the aircraft nor the frequency of each different mission is known. Mission cost, a lower level costing approach, best described those elements of cost affected by automating cargo handling inside Army aircraft.

Stated in equation form,

$$\begin{array}{c} \text{Total} \\ \text{Mission} \\ \text{Cost} \end{array} = \begin{array}{l} \text{Delivery} \\ \text{System} \\ \text{Investment} \\ \text{Cost per} \\ \text{Mission} \end{array} + \begin{array}{l} \text{Delivery} \\ \text{System} \\ \text{Operating} \\ \text{Cost per} \\ \text{Mission} \end{array} + \begin{array}{l} \text{Cost of} \\ \text{Replacing} \\ \text{Lost Aircraft} \\ \text{per} \\ \text{Mission} \end{array}$$

Each delivery system will have a unique total mission cost associated with each mission it is assigned to perform.

Because of the narrow scope of the problem, detailed cost categories were required in order to measure adequately the costs attributable to increased automation of cargo handling functions. Consequently, the calculation of total mission cost involved costs per flight hour, per ground hour, per ton loaded, and per operating day.

The average number of operating aircraft, tons transported, aircraft lost, ground hours, and flight hours per operating aircraft are inputs from the effectiveness analysis to the cost analysis.

Integration of Cost and Effectiveness

The integration of cost and effectiveness is complicated by the fact that either or both may be increasing or decreasing as the degree of automation increases. For this reason, no approach based on ratios is advisable, although some reasonable relationship between cost and effectiveness is required.

Two approaches were utilized in this study: (1) trend analysis plots and (2) rate of return plots. The first involves simply plotting both cost and effectiveness against the automation index, or measure of the degree of automation of each cargo handling system. These plots permit observation of the absolute cost and effectiveness trends as the degree of cargo handling system automation is increased from manual to fully automated.

The second means selected was to express the differences in cost and effectiveness between automated systems and the manual base case as percentage changes from the manual case values and to plot these percentage changes as a function of the percentage increase in automation index. The percentage change could be either positive or negative, and may be displayed graphically. In addition to establishing the approximate optimum range of cargo handling system automation, this technique permitted the analyst to observe rates of change, plateaus, and inflection areas.

The overall flow of the analysis is shown in Figure 1.

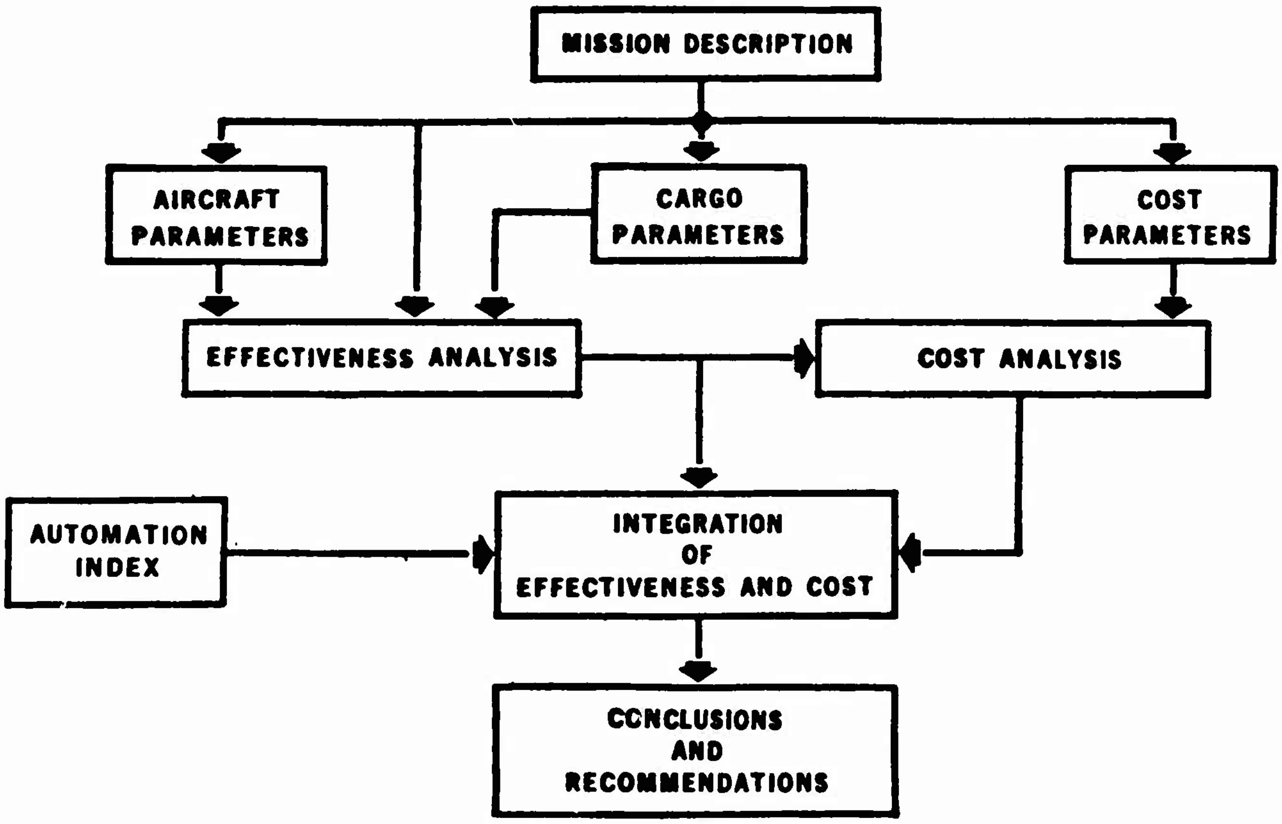


Figure 1. Flow Analysis

DATA DEVELOPMENT

The objective of Phase II of this study was to evaluate the effectiveness and cost of automated cargo handling systems by using techniques developed in Phase I. The evaluation required developing data in the areas of missions, combat environment, aircraft factors, cargo handling systems, cargo loads, cargo handling time, aircraft costs, and cargo handling system costs.

Six cargo handling systems were chosen from thirteen considered. The automation index for each of the six systems for each cargo type was determined by using the functional evaluation method developed during Phase I of the study. The systems ranged from completely manual to very highly automated. The systems evaluated were (see Figure 2):

1. A bare aircraft with a wheeled pry bar and plywood shoring.

2. Friction reducing Nylatron rub strips with a winch.

3. Skate wheel conveyors with buffer boards and a winch.

4. Roller conveyors, guide rails (with integral pallet latches), specialized cargo platforms, and a winch.

5. Roller conveyors, guide rails (without latches), specialized cargo platforms, and a carwash-type chain in the aircraft floor which provides for cargo movement and restraint in forward and aft directions.

6. A full-floor-width, powered conveyor belt with an automatic overhead cargo net restraint system.

Each system was supported with adequate preliminary design analysis to allow estimation of the weights and costs of the system.

The six systems selected were each evaluated in four aircraft. Three are current aircraft (CV-2, CV-7, and CH-47) and one is a hypothetical 10-ton STOL.

Data developed for the four aircraft evaluated included: flight times, fuel consumption, payload/radius, availability, refueling rate, fuel capacity, cargo compartment dimensions, and restraint factors.

The criterion for evaluation was the performance of hypothetical missions. Mission A was the deployment of the Airmobile Division and daily resupply of an Air Assault Division. Mission B was the daily resupply of the forward elements of a ROAD Infantry Division. Supplies were delivered by landing and unloading (airland) and by airdrop. The cargo for the missions included vehicles, troops, palletized supplies, bulk supplies, and petroleum, oil, and lubricants (POL). Each mission required the delivery of a fixed cargo quantity in a fixed time period.

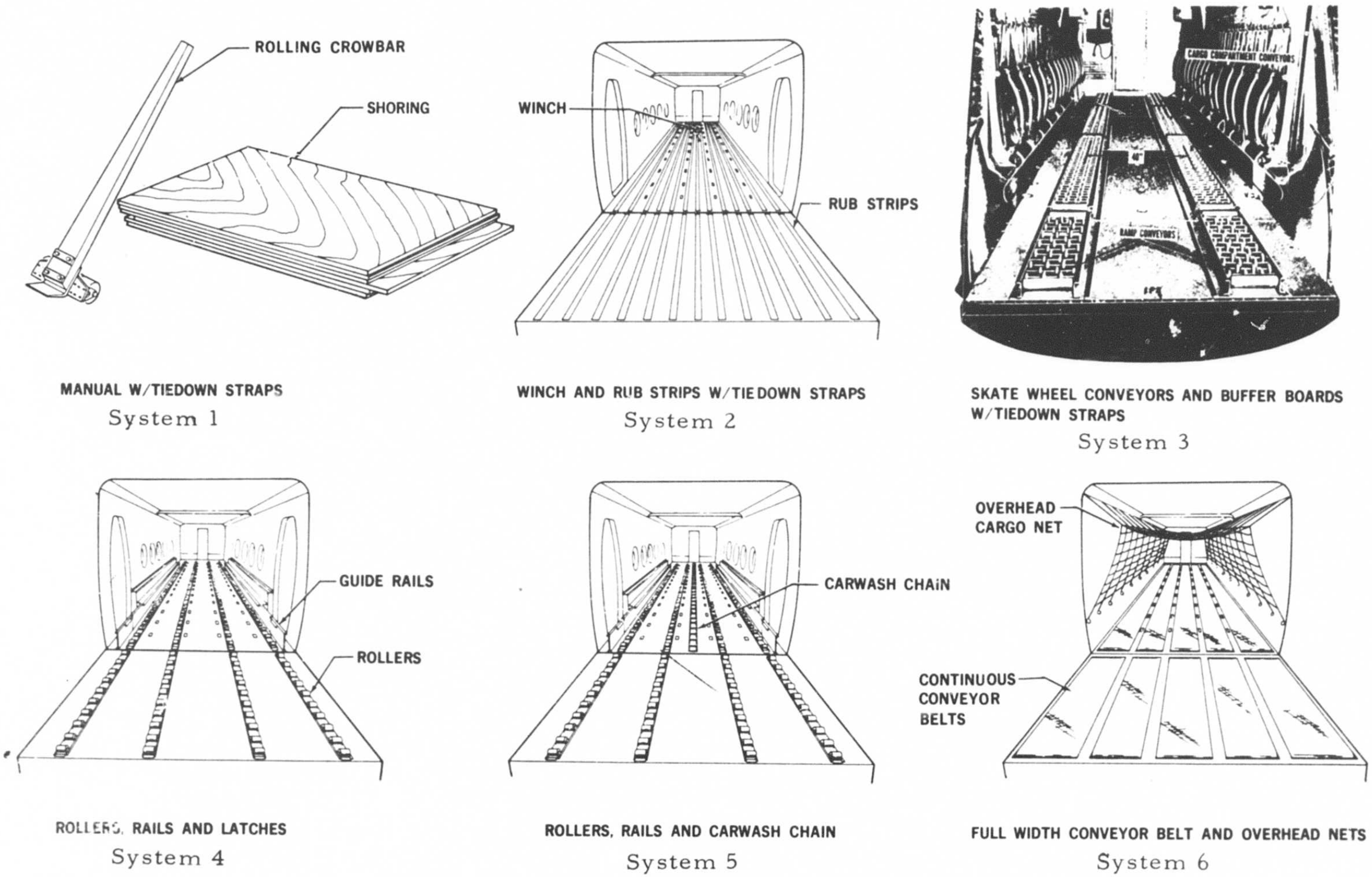


Figure 2. Degrees of Cargo Handling System Automation Evaluated

To allow accurate predictions of cargo handling time with each system, specific type-loads were developed for each aircraft. As cargo handling system weight increased, cargo was removed from the load in order to evaluate the effect of cargo handling system weight on the aircraft effectiveness. This assumption is conservative in that it assumes that every aircraft will be grossed out whenever it is not volume limited.

Cargo handling time was analyzed by using the loads defined for a particular aircraft. The method used estimated the time required to perform each function involved in loading, restraint, and unloading; manpower requirements; and the effect of functions performed concurrently by different crew members.

Mission costs, comprised of investment, operating, and loss costs, were developed for all cargo delivery systems analyzed. The initial investment cost of each of the four aircraft consisted of its flyaway cost and initial support cost. For the six cargo handling systems, an investment cost was developed, comprised of research and development costs (when applicable), unit (flyaway) cost, and initial support cost. Operating costs for each cargo delivery system (aircraft plus cargo handling system) were developed, the cost being a composite total of operating costs based on flight hours, ground hours, tons of cargo loaded, and operating days per mission. The total loss cost per mission was calculated based upon the replacement cost of cargo delivery systems downed and not repairable.

Two methods of computing weight and balance were evaluated: manual and automated. Manual weight and balance involves completely manual effort, and therefore no weight penalty or investment cost is accrued. The automated weight and balance system had weight and investment cost penalties due to the sensors in the landing gear, computer, and gauges added to the aircraft. Figure 3 shows the breadth and depth of the evaluation

RESULTS

No quantitative effectiveness gains or cost savings were found to result from automating cargo handling functions in the CV-2.

For airland resupply, the primary Army aircraft mission, effectiveness decreased exponentially to a maximum penalty of almost 30 percent* for system 6 in Figure 2. Cost increased almost linearly to about a 30-percent penalty for system 6.

*All percentage changes noted in this section are relative to the effectiveness or cost of system 1, the manual base case system, in Figure 2.

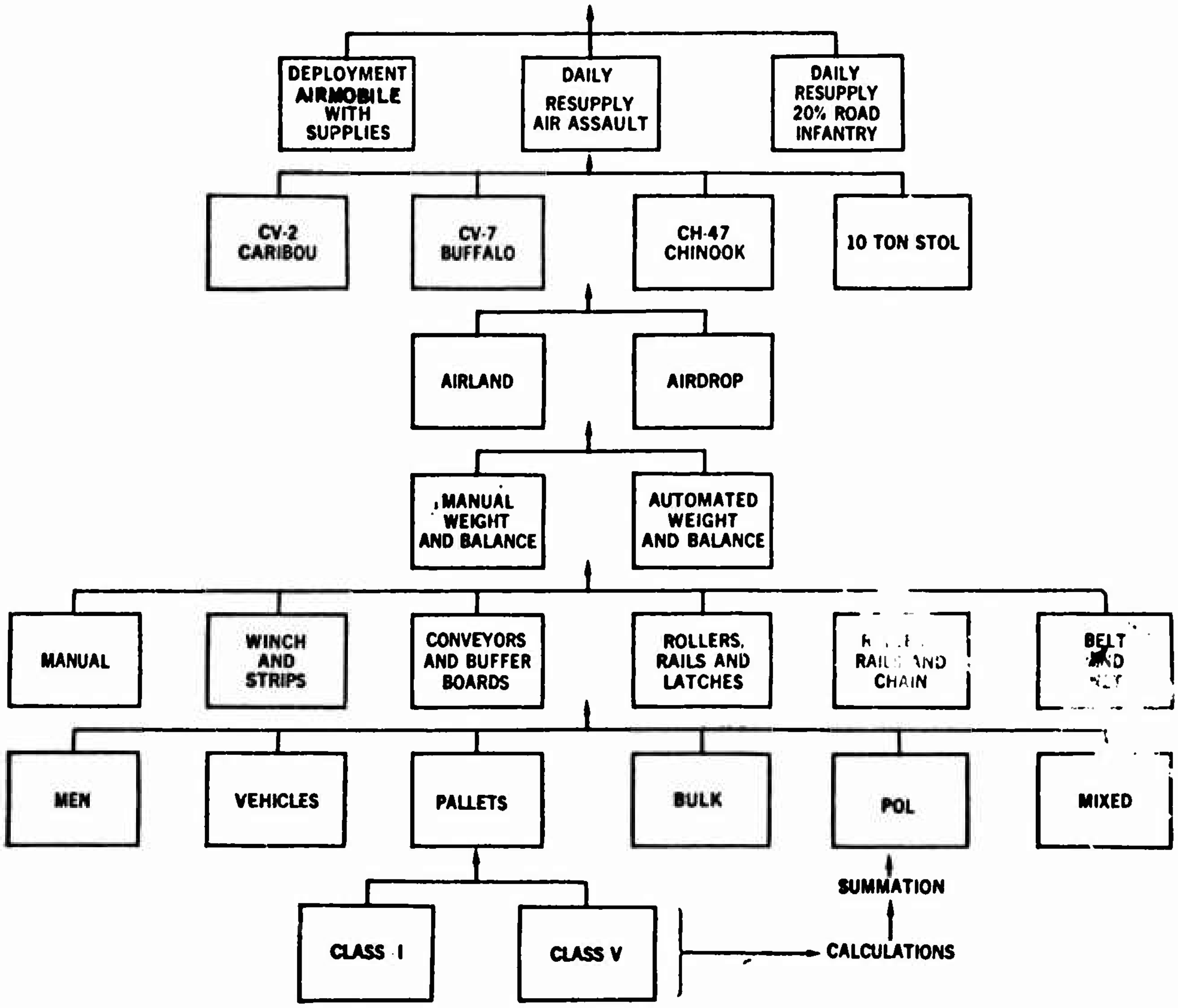


Figure 3. Cases Evaluated

To airdrop from the CV-2, some system is required to reduce floor friction and to provide side guidance. Systems similar to systems 3 and 4 in Figure 2 will allow airdrop from the CV-2 and will result in effectiveness penalties from 2 percent to 3 percent and cost increases of 3 percent to 11 percent.

The addition of cargo handling equipment to the CV-2 has a negligible effect on cost and effectiveness for the deployment mission, as the aircraft is often volume limited, except for system 6 where 15-percent penalties accrue.

Effectiveness gains and cost savings are possible from automating cargo handling functions in the CV-7, the former over a relatively wide automation range and the latter only at low degrees of automation.

For airland resupply, effectiveness gains ranging from 3 percent to a maximum of 10 percent are possible. The lower effectiveness increases have corresponding cost savings of up to 5 percent. Either negligible cost savings or cost penalties ranging from 1 percent to 8 percent accompany the maximum effectiveness gains. Effectiveness and cost deteriorate significantly for very highly automated systems, effectiveness decreasing as much as 15 percent and cost increasing as much as 33 percent. Systems 2, 3, and 4 in Figure 2 lie near the optimum automation range for the CV-7.

Systems similar to 3 and 4 are capable of airdrop.

For the deployment mission, cost and effectiveness are essentially unaffected by the cargo handling system installed in the CV-7, except at very high degrees of automation (system 6) where 17- to 19-percent penalties were evidenced.

For the hypothetical 10-ton STOL, both cost and effectiveness gains were evident over wider ranges of automation than with the CV-7.

For the airland resupply missions, the maximum decrease in cost of 3 percent to 6 percent was accompanied by a 7-percent to 11-percent increase in effectiveness; the maximum effectiveness increase of 10 percent to 14 percent was accompanied by essentially neutral cost changes, ranging from a 4-percent decrease to a 3-percent increase.

System 4 was most effective and least costly for airdrop from the 10-ton STOL.

For the deployment mission, the 10-ton STOL was not volume limited due to its wide floor. The changes in cost and effectiveness were generally related to the weight of the cargo handling system. Changes were minimal except for very high degrees of automation (systems 5 and 6), where 8- to 15-percent penalties accrued.

Significant effectiveness gains and small cost savings were evidenced for the CH-47.

Corresponding to the maximum cost savings of about 3 percent are effectiveness gains of 11 percent to 14 percent for the airland resupply mission. The effectiveness gains remain high up to very high degrees of automation. Cost penalties never exceeded 10 percent, even for system 6.

The CH-47 was not evaluated for airdrop.

Due to the large payload of the CH-47 for the short deployment mission radius, the aircraft was volume limited except at very high degrees of automation. Consequently, cost and effectiveness are relatively independent of the cargo handling system installed in the CH-47 for this mission.

The addition of an automated weight and balance computation system to any of the four aircraft evaluated resulted in increased effectiveness and decreased cost.

CONCLUSIONS

Cost and effectiveness benefits are possible from automating cargo handling functions in Army aircraft. These benefits increase as the size and/or speed of the aircraft increases or as the mission radius decreases.

Only the minimum automation required for airdrop is justified for the CV-2 Caribou.

A system similar to the skate wheel and buffer board system appears optimum for the CV-7 Buffalo, the CH-47 Chinook, and the hypothetical 10-ton STOL, in that it offers near maximum effectiveness and small cost savings. The slight cost penalties with the roller, rails, and latches system might be justified, depending on the place of airdrop in the Army missions.

Vehicle loads are generally volume limited in present Army aircraft.

An automated weight and balance system is justified in all four aircraft.

The results of the study are conservative in that the aircraft were loaded to their maximum available payload and the weight of the cargo handling systems had its maximum detrimental effect on aircraft productivity.

INTRODUCTION

PROBLEM STATEMENT

The need for organic transport capability by Army aircraft in support of highly mobile combat operations is resulting in increased emphasis on high performance delivery capabilities. System interrelationships involved in the delivery of supplies and equipment by aircraft are complex and have major effects on aircraft design and performance as well as on ground supporting systems. Currently, air cargo handling ranges from manual individual package handling to sophisticated, highly automated systems (Air Force 463L type). Technology to support any desired degree of automation of the delivery function is or will shortly become available.

The Army has a growing organic air transport capability, both fixed and rotary wing. Operational requirements and monetary limitations cause a pressing need for the Army to obtain the highest efficiency in the delivery capabilities of present and future Army aircraft.

Efficiency in the delivery of cargo implies speed. The speed with which materiel can be delivered to a given point is a function of many variables. One of the most important of these is the speed with which the cargo handling functions may be performed. There are various means of improving the speed of cargo handling. For the purpose of this contract, these have been called levels or degrees of automation. Countering any increases in speed derived from automating cargo handling functions are the penalties accruing due to the weight of the cargo handling equipment.

Army ALOC missions involve transporting small loads over short distances to an exact, and probably primitive, area. Current Army aircraft reflect the nature of the Army missions: they are designed to carry small payloads over short distances and to operate from forward area facilities. Since Army mission radii are short, especially for helicopters, cargo handling time is a significant part of the total cycle time. Savings in cargo handling time resulting from automating cargo handling functions are accordingly significant. Since the payloads transported are small, the degradation of the available aircraft payload due to the weight of any cargo handling equipment added to the aircraft is likewise significant.

There is a need for the Army to establish a basis for decision as to the degree of cargo handling system automation required in its transport aircraft. It is the purpose of this program to conduct a cost/effectiveness evaluation of automated delivery systems for fixed- and rotary-wing transport aircraft, based on the operational concepts and descriptions of typical support missions as defined in the subject contract.

SCOPE

The purposes of this study are to develop means of measuring the gains and penalties resulting from automating cargo handling functions in Army aircraft and then to define the approximate degree of cargo handling system automation desirable in Army aircraft.

The study effort was divided into two consecutive phases. During the 3 months of Phase I, cost and effectiveness techniques were developed to analyze the narrow area of automated cargo handling systems in Army aircraft. Methodologies were developed to measure

1. The degree of automation inherent in a particular cargo handling system.
2. The effectiveness resulting from a particular cargo handling system in meeting a given ALOC mission requirement.
3. The cost associated with fulfilling a mission requirement with a given cargo handling system.
4. The relationship between effectiveness and cost for a spectrum of degrees of automation.

Following approval of the methodology developed in Phase I, a 2-month Phase II effort was initiated. During this phase, several cargo handling systems were evaluated in three fixed-wing and one rotary-wing Army aircraft. A wide range of degrees of automation was represented by the systems evaluated. Data were developed for three airland and two airdrop missions, including the required mission, aircraft, and cargo parameters. In addition, the whole evaluation was performed with and without an automated weight and balance computation system in the aircraft.

Because the study centers about relatively small changes in cargo handling system weight and cargo handling time resulting from specific hardware additions to the aircraft, a deterministic approach was used.

The study results are conservative. This conservatism is due to the fact that aircraft were loaded to their full available payload (unless volume limited); therefore, the payload degradation due to the weight of cargo handling equipment added to the aircraft had its maximum detrimental effect on aircraft productivity.

The object of the study was to define the approximate degree of cargo handling system automation desirable in Army aircraft, rather than to select specific cargo handling systems for the aircraft evaluated. While cargo, mission, and aircraft parameters were defined to serve as an

evaluation framework, the purpose remained to evaluate cargo handling system automation, not the aircraft used as evaluation vehicles. Detailed examination of ground handling subsystems was contractually outside the scope of the study.

AUTOMATION INDEX

INTRODUCTION

Automation in a gross sense includes everything from a lever to a computer and is difficult to quantify. How automated one task is relative to another is further complicated because there is no accepted unit of measure for automation. (A measure of so many automations per pound of equipment would be ideal.) Industry makes decisions on which or how much automated machinery to buy based on an economic analysis of the return expected per dollar invested. When dealing with military forces, the value of delivering a ton of supplies to a combat unit which needs the supplies is difficult to measure in dollars and cents.

One of the primary objectives of the study was the development of a quantitative measure of the amount of automation inherent in cargo handling systems. The quantitative measure would then provide the basis for an analysis of the returns possible from automating cargo handling tasks.

SCOPE

The measure of automation (hereafter called the automation index) will apply only to the cargo handling system within the aircraft. The total cycle of cargo delivery requires the performance of many operations prior to the cargo's arriving at the aircraft (i.e., select cargo for transport, prepare cargo, transport cargo to aircraft, etc.). These operations are excluded from consideration by contract. Likewise, operations which are performed after the cargo leaves the aircraft are excluded.

Computation of aircraft weight and balance was not included in the automation measure because the weight and balance system is independent of the cargo handling system. The study of automating weight and balance in an aircraft can be accomplished either simultaneously or independently. The effect of automating weight and balance on system productivity is the degradation of payload due to the weight of the unit and the decrease of ground time because of a decrease in weight and balance time. To show the effect of automating weight and balance, the cost and effectiveness analyses will be made for:

1. Manual weight and balance.

2. Highly automated weight and balance.

DEFINITION OF AUTOMATION

For the purposes of this study, automation is defined as the reduction of human energy input or human decision in a cargo handling operation or task by the addition of equipment to an aircraft.

CRITERIA FOR SELECTION OF AUTOMATION MEASURE

It is the intent of this study to define a measure of automation that will allow rating of the relative amount of automation in existing or proposed cargo handling systems. Criteria were established to evaluate possible rating methods. The rating method must:

1. Be independent of the effectiveness measures. (This is necessary because a highly automated system may be ineffective.)

2. Be independent of cost measures.

3. Allow for the relative rating of present as well as future cargo handling systems prior to detail design.

4. Differentiate between similar but not identical cargo handling systems.

5. Allow consistent rating of the same system by different evaluators.

6. Reflect the amount of hardware in a system. (A system with a higher index would probably be heavier and more complex.)

7. Be dependent only on the actual hardware in a cargo handling system and insensitive to the particular type of cargo being transported.

APPROACHES CONSIDERED

Several approaches initially appeared to be reasonable for measuring automation. As will be described in the following text, each method investigated has definite failings when subjected to close scrutiny. The methods investigated included: time, manpower, time and manpower, man-hours, and functional rating. A definition of each of the possible methods is given below.

Time

Time as a measure of automation includes that time required to move the cargo from a loading vehicle into position in the aircraft and to attach the required restraint. Time to prepare cargo prior to loading and time to position cargo handling ground equipment adjacent to the aircraft are not included.

Manpower

As with time, manpower includes only those men required to load and restrain the cargo within the aircraft. Manpower required for servicing functions and cargo handling prior to arrival at the aircraft is not included.

Time and Manpower

The definition of this measure is the same as when each is used separately.

Man-Hours

Man-hours, as with time and manpower, are restricted to the actual man-hours required to load, restrain, release restraint, and unload cargo.

Functional Evaluation

The functional evaluation technique requires that all functions for loading, restraining, and unloading cargo be defined. In addition, the degree of automation must be numerically rated. By examining the manner in which each function is performed with a given cargo handling system, it is possible to select the appropriate rating for the function. Determination of the ratings for all functions establishes the automation index for that specific system.

RATIONALE FOR SELECTION OF METHOD

One criterion for selection of a method of determining the automation index was that it must be independent of effectiveness. Manpower and the functional evaluation method are the only approaches which met this criterion.

The second criterion for selection was that the method must be independent of cost. Time and the functional evaluation method met this criterion. Time is, however, indirectly linked with cost through man-hours.

The third criterion was to allow rating of the system prior to detail design. All of the approaches considered met this criterion.

The fourth criterion was to differentiate between similar but not identical cargo handling systems. The relationshp of time and manpower and the functional evaluation method were the only two approaches which satisfied this criterion.

The fifth criterion was that the rating must be consistent for the same system with different evaluators. All of the approaches investigated satisfied this criterion.

The sixth criterion was that the rating must reflect the amount of hardware in a cargo handling system. The only approach which did not satisfy this criterion was the relationship between time and manpower.

The seventh criterion for selection of a method of measuring automation was that the measure should be independent of a particular cargo type. All of the approaches considered were found to be dependent on the cargo type. None met the criterion.

As a result of the above examination of possible approaches, the functional evaluation method of determining the automation index was selected because it satisfies more of the evaluation criteria than any of the other approaches considered.

DETAILED DESCRIPTION OF SELECTED APPROACH

An analysis was performed to determine the functions required in the cargo handling cycle. The first level functional diagram consists of six blocks, as shown in Figure 4.

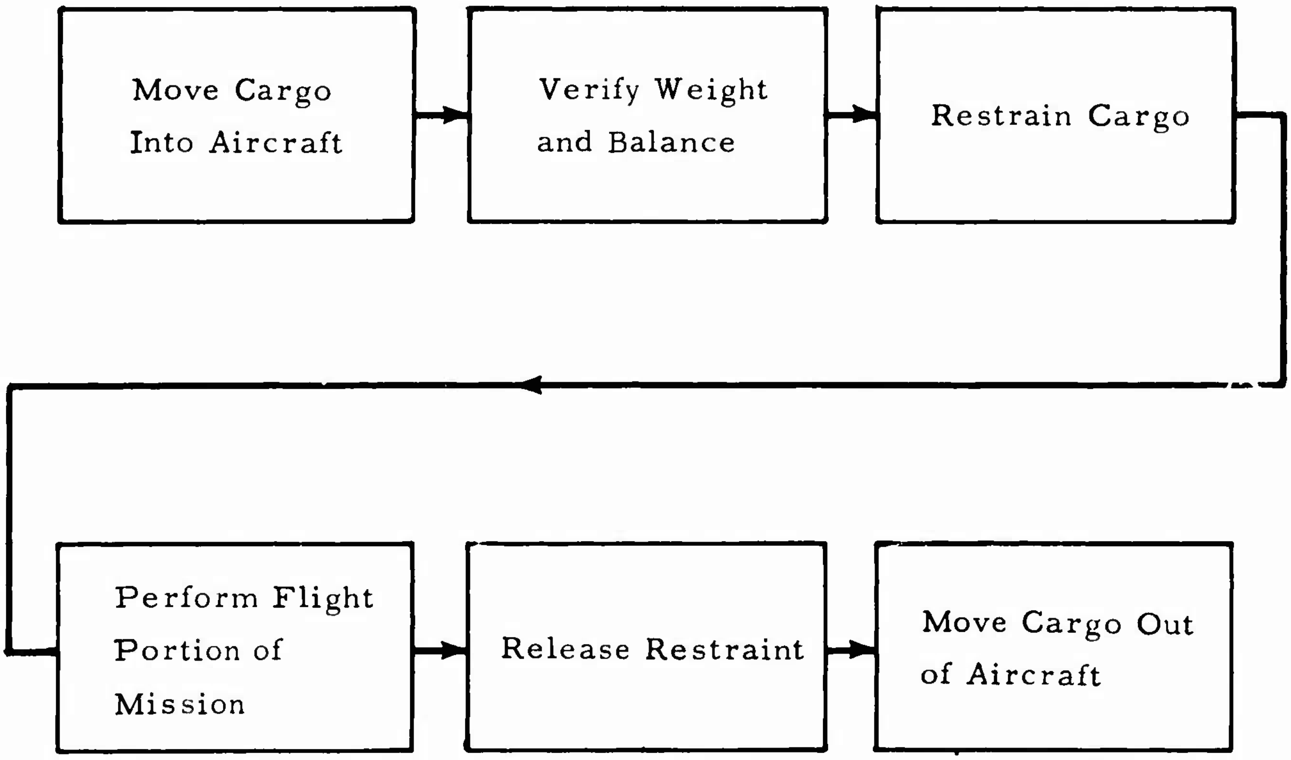


Figure 4. First Level Functional Flow Diagram

A second level breakdown (Figure 5) was made in the blocks which were specifically concerned with cargo handling operations. Definitions of each function are shown in Table I.

The cargo handling functions could not be detailed beyond the second level and still be general enough to apply to any system. (An additional level breakdown could be made, but it would be almost a task analysis of a particular system.)

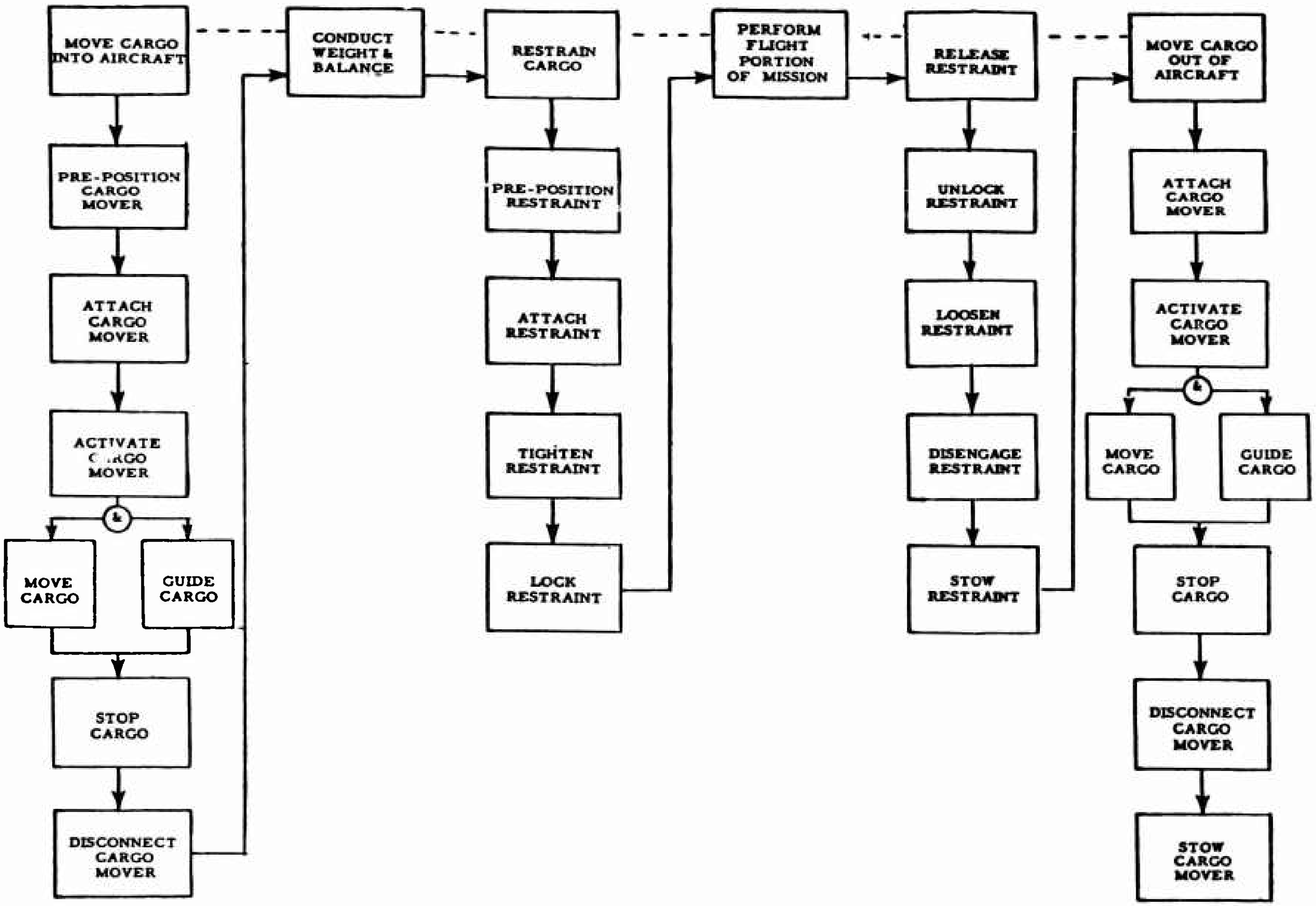


Figure 5. Second Level Functional Flow Diagram

TABLE I

DEFINITIONS OF FUNCTIONS

Function	Definition
Pre-position Cargo Mover	The relocating (if required) of the means of providing the power to move the cargo (man, winch, overhead crane, etc.).
Attach Cargo Mover	The contact of the cargo mover with the cargo.
Activate Cargo Mover	Putting the cargo mover into motion.
Move Cargo	This function is performed by the cargo mover, but the ease with which it is performed is dependent on the type of system; i.e., rollers will allow the function to be performed easier than a floor with some kind of rub strips.
Guide Cargo	This function happens when the cargo is being moved; however, it is not necessarily performed simultaneously in the sense that it would receive maximum rating. Each system must be evaluated in the light of how the guidance is provided.
Stop Cargo	Bring the cargo to rest.
Pre-position Restraint	Includes such things as laying out tiedown chains or "locking" pallet latches (if required).
Attach Restraint	Bringing the restraint means into contact with the cargo.
Tighten Restraint	Taking slack out of tiedown chains or cargo nets.
Lock Restraint	Securing the restraint in such a manner that it will not inadvertently be released. When this function is complete, the cargo should require no additional attention until the aircraft is airborne.

Note: Only the loading functions are shown, because the loading and unloading functions are essentially the same.

There are functions which must be performed with a given cargo handling system which affect, but are not directly related to, the cargo handling procedure; i.e., a roller conveyor system may require that the rollers be stowed prior to loading vehicles. This type of function, since it is not required for all cargo handling systems, is discussed in the section entitled "Other Considerations" when it is required by a particular system.

The rating system is an orderly progression between completely manual and fully automated. There are seven possible ratings (Figure 6). The number of ratings could be expanded considerably, but as more steps are added, the choice of the applicable rating for a particular function becomes more difficult. A decision was made to use a large number of functions and a small number of ratings. The selected method is a logical balance between number of functions and number of ratings. The evaluator is required to make a number of relatively simple decisions in arriving at the automation index for a particular system.

The functional analysis was performed in a manner that would assure a definite requirement to perform every function defined, regardless of the cargo handling system configuration. Because of this, every function must be assigned a rating.

To evaluate the degree of automation present in a particular cargo handling system, the analyst considers the first function involved in loading, rates the degree of automation of that single function, then proceeds to the next function, and so on, until the degree of automation of the last unloading function has been evaluated. When all functions have been evaluated, the automation index for the system is obtained by totaling the ratings of all functions.

Because of the difference in equipment required to handle various types of cargo, it is necessary to determine the automation index of a cargo handling system with reference to a particular cargo type. Five general classifications of cargo are carried in Army aircraft: palletized supplies; vehicles; bulk (supplies not palletized); petroleum, oil, and lubricants (POL); and passengers. A cargo handling system (capable of accommodating any of the five types of cargo) installed in an aircraft will be assigned a separate automation index (I_Y) for each type of cargo.

The evaluator must rate the automation of the cargo handling system, not the cargo. That is, to determine the automation index for a particular cargo handling system for vehicles, one must assume that the vehicles being loaded are non-self-propelled. Although self-propelled vehicles may be loaded faster under their own power, this increased speed of loading is not attributable to the cargo handling system.

The same situation exists with men as with vehicles. The power for movement of the cargo (men) is provided by the cargo itself, but does not represent automation of the cargo handling system.

RATING			FUNCTION: Pre-Position Cargo Mover	Attach Cargo Mover	Activate Cargo Mover	Move Cargo	Guide Cargo	Stop Cargo	Disconnect Cargo Mover	Pre-Position Restraint	Attach Restraint	Tighten Restraint	Lock Restraint	Unlock Restraint	Loosen Restraint	Disengage Restraint	Stow Restraint	Attach Cargo Mover	Activate Cargo Mover	Move Cargo	Guide Cargo	Stop Cargo	Disconnect Cargo Mover	Stow Cargo Mover
DESCRIPTION		VALUE																						
Fully automated (power and decision provided by the materials handling system or because of the system design the performance of the function is accomplished simultaneously with another function).		6																						
Powered devices, decision provided by man		5																						
Manual With Non-Powered Devices	Most work done by the MHS Decision by MHS	4																						
	Most work done by the MHS Decision by man	3																						
	Most work done by man Decision by MHS	2																						
	Most work done by man Decision by man	1																						
Manual--All work and decision by man		0																						

Figure 6. Automation Index Evaluation Form

It is possible to combine all five indexes (i.e., vehicles, pallets, bulk, passengers, and POL) into a single number based on a weighted index dependent on the quantity of each type of cargo transported. To do this, a specific mission must be defined with definite quantities of each cargo type. The indexes are then combined according to the following formula:

$$I = \sum \frac{I_Y \cdot C_{TY}}{C_T} \tag{1}$$

where

I = Automation index

Y = Type of cargo (pallets, vehicles, etc.)

C_{TY} = Tons of a particular type of cargo

The limitation of this method of combining indexes is that the composite automation index is highly dependent on the mission defined. The distribution of cargo quantity by cargo type will vary with various missions; therefore, two different missions will result in two different composite automation indexes for the same hardware.

Three problems of interpreting the approach to rating the automation of a cargo handling system require discussion:

1. The possibility of weighting the automation of one group of functions more than another (e.g., rating the automation of loading functions higher than the automation of unloading functions).

2. Functions which initially do not appear to be performed at all with a particular cargo handling system.

3. The manner of rating the degree of automation for functions which are performed simultaneously (and perhaps instantaneously) by a particular cargo handling system.

The weighting of functions would attempt to establish the importance of functions. It is not the purpose of the automation index to measure the value of automating one function compared to another, but to rate the amount or degree of automation of a whole cargo handling system for performing each function. The gains or penalties derived from various degrees of automation are measured by the effectiveness analysis, not by the automation index. Weighting functions tend to evaluate the importance of automating cargo handling, not to establish whether it is automated per se, and are not appropriate.

The discrete functions defined in Table I must be performed in any cargo handling operation. In some cases they are performed in a different manner, but they are still performed; e.g., attaching a winch to a pallet or a man's placing his hands behind the pallet in order to push it is still the function of attaching the cargo mover to the cargo. The function "attach cargo mover to cargo" has been performed manually in both cases. One may be more realistic and more efficient, but neither is automated. To use the functional evaluation method, the analyst rating the degree of automation of particular systems must assume that all functions are performed with each system and must rate each function.

If several functions are performed simultaneously (and perhaps instantaneously) by a particular automated cargo handling system, they have still been performed and must be rated. The same reasoning as above applies. Functions which are automatically executed by the performance of another function would be assigned a rating of six (i.e., fully automated) if no manual energy or decision is necessary in order to perform them.

AUTOMATION INDEX SAMPLE CALCULATION

This example of the calculation of the automation index was prepared [illegible] in the understanding of the functional evaluation method.

The system to be evaluated consists of rollers, guide rails, integrated latches, and an integrally mounted winch. The system automation index will be determined for palletized cargo utilizing the winch. Pallets can be loaded by pushing them into position with manpower; however, since a winch is included in the system, it must be included in the automation index calculation.

Table II shows each function for the loading cycle, the rating assigned in Figure 7, and the explanation of the choice of rating. The off-load cycle is essentially the reverse of the on-load cycle in this example, and ratings do not change.

It is interesting to note that the winch, although it adds to the automation, would detract from the effectiveness of the system for handling pallets. This is because of the time-consuming rigging required.

Automation Index Example Cases

The objective of this section of the report is to show examples of application of the automation index in a variety of cases. The cases selected may not be the most logical selection of cargo systems from an operational viewpoint nor from a cost or effectiveness viewpoint. However, the cases are a representative cross section of cargo systems having a wide spread in automation index ranging from zero to 100 percent automated. The evaluation of each system is for palletized cargo.

TABLE II

EXAMPLE – AUTOMATION INDEX RATING

Function	Rating	Reason
Pre-position Cargo Mover	6	The winch is integrally mounted in the aircraft and does not require pre-positioning; therefore, since the function is not performed, it is completely automated.
Attach Cargo Mover	0	This requires a man to walk the winch cable to the pallet and attach it to the pallet. The man must provide the work and decision.
Activate Cargo Mover	0	The winch is assumed to be controlled by a push-button control, and a man must make the decision to move the cargo and provide the work to actuate the winch.
Move Cargo	5	Power for the movement is provided by the winch, but man provides the decision.
Guide Cargo	4	Guide rails provide the guidance and decision; but since the guide rail is not powered, the maximum value that can be assigned is 4.
Stop Cargo	0	Man, through the control of the winch, provides the decision and work to stop the cargo.
Disconnect Cargo Mover	0	This requires a man to disconnect the winch cable from the pallet. He must provide the decision and work.
Pre-position Restraint	6	In this system the latches are integral with the guide rail and do not require positioning.
Attach Restraint	6	The latching system is a two-location-type latch being either open or closed; therefore, the attachment and tightening take place during the locking operation which is accomplished by a man manually moving a lever.
Tighten Restraint	6	
Lock Restraint	0	

Note: The unload cycle is not shown because it is essentially the reverse of the load cycle.

Load | Rest

RATING: DESCRIPTION		VALUE	Pre-Position Cargo Mover	Attach Cargo Mover	Activate Cargo Mover	Move Cargo	Guide Cargo	Stop Cargo	Disconnect Carg Mover	Pre-Position Restraint	Attach Restraint	Tighten Restraint	Lock Restraint	Unlock Restraint	Loosen Re	Dise	
Fully automated (power and decision provided by the materials handling system or because of the system design the performance of the function is accomplished simultaneously with another function).		6	X							X	X	X			X	X	X
Powered devices, decision provided by man		5				X											
Manual With Non-Powered Devices	Most work done by the MHS Decision by MHS	4					X										
	Most work done by the MHS Decision by man	3															
	Most work done by man Decision by MHS	2															
	Most work done by man Decision by man	1						X									
Manual – All work and decision by man		0		X	X				X				X	X			

Figure 7. Example System Evaluation

	Load							Restraint				Release				Off Load						
VALUE / FUNCTION	Pre-Position Cargo Mover	Attach Cargo Mover	Activate Cargo Mover	Move Cargo	Guide Cargo	Stop Cargo	Disconnect Cargo Mover	Pre-Position Restraint	Attach Restraint	Tighten Restraint	Lock Restraint	Unlock Restraint	Loosen Restraint	Disengage Restraint	Stow Restraint	Attach Cargo Mover	Activate Cargo Mover	Move Cargo	Guide Cargo	Stop Cargo	Disconnect Cargo Mover	Stow Cargo Mover
6	X							X	X	X			X	X	X							X
5				X														X				
4					X														X			
3																						
2																						
1						X														X		
0		X	X				X				X	X				X	X				X	

Rating 68

Evaluation

B

Selection of a system having a zero degree of automation is not easy, in that even cargo tiedown devices of simple construction can have a degree of automation above zero. A zero automation index must be entirely manual; furthermore, no tools providing a mechanical advantage can be used.

The system selected for Case I (zero automation) is completely manual, wherein none of the functions identified in the functional index contain mechanical advantage devices. Rope was selected for tiedown to avoid automating the restraint latching portion of the tiedown function. This system, while it may fall short in a cost effectiveness evaluation, actually has been used even recently as an interim expedient when an insufficient quantity of equipment has forced improvisation to get a job done.

The definition of a number of systems, each with progressively increasing automation, requires the following basic procedure: Select a functional element (such as tiedown) and define in progressive steps hardware which has a slight improvement in automation rating. Continue the improvement in the first selected function until no apparent improvement in automation level is possible without also considering improvement in adjacent functional areas. Select the next functional area and repeat the automation improvements for it until fully exploited. Continue through all functional areas in the same fashion.

After one cycle of improvements in all functional areas, inspection of the results will reveal that, because of the close interdependence of one functional area on the other, automating one will allow greater automation of another. By recycling the automation improvement of each functional element in a total system several times, a final system can be defined which will have a very high automation rating.

An example of this approach for 17 different systems will clarify the procedure. See Figure 8 for ratings.

System 1 – Automation Index = 0

This system consists of an aircraft cargo compartment equipped with cargo tiedown rings. Cargo is moved into the aircraft by using manpower either by carrying or sliding cargo into position. Restraint of cargo is accomplished by using rope. Because all functions are performed manually, the system has an automation index of 0.

System 2 – Automation Index = 6

This system is identical to system 1 except that a cargo strap with a military belt-type buckle is used for restraint. This buckle provides automatic locking with the tightening function; however, the buckle must be unlocked before loosening. Because the locking is performed simultaneously with the tightening function, it is assigned a value of 6. The loosening and

unlocking functions both require manual effort and are therefore assigned ratings of 0.

System 3 – Automation Index = 12

This system is identical to system 2 except that an MB-1 tiedown strap is used in place of the strap with a military-type buckle. The MB-1 strap is locked when tightened and is loosened when unlocked; therefore, the locking and loosening functions are fully automated. As with system 2, the locking function is assigned a rating of 6. The loosening function is performed simultaneously with the manual unlocking function. Loosening is assigned a value of 6, and unlocking is assigned a value of 0.

System 4 – Automation Index = 18

This system is the same as system 3 except that a cargo net, suspended from the ceiling of the aircraft, is used for restraint. The cargo net is manually attached to floor tiedown rings by using MB-1 type fittings. In this case, the locking, loosening, and pre-positioning of restraint are automatic. Each of these functions is assigned a value of 6.

System 5 – Automation Index = 24

This system uses the same restraint method as that described in system 4. The movement of cargo into and out of the aircraft is aided by the addition of a wheeled pry bar (Johnson bar). The wheeled pry bar provides most of the effort required to move the cargo. The decision to move the cargo is provided by man. The function "move cargo" in both the load and the unload cycle is assigned a value of 3.

System 6 – Automation Index = 28

This system is the same as system 5 except that the pry bar is motorized. This changes the value of the movement functions from 3 to 5.

System 7 – Automation Index = 32

This system uses the same restraint means as systems 4, 5, and 6. The method of movement of cargo is changed in this system. The pry bar is deleted and skate-wheel-type conveyors are added. Cargo is preloaded on plywood sheets to allow the use of rollers. In this case, the function of moving cargo is rated at 3 and the function of guiding cargo is also rated at 3. The guidance of cargo on a roller system is relatively easy because of the unidirectional characteristic of rollers or fixed axle wheels. Stopping of cargo is rated at 1 because the friction in the rollers aids slightly in bringing the cargo to rest.

	MOVEMENT	GUIDANCE	RESTRAINT	FUNCTI Pre-Positio	Attac
1	Manpower Bare Aircraft	Manpower	Rope - Integral Tiedown Rings		
2	" " "	"	Strap w/ Military Buckle		
3	" " "	"	MB-1 Tiedown Strap		
4	" " "	"	Overhead Cargo Net		
5	Manpower and a Wheeled Pry Bar	"	" " "		
6	" Motorized Pry Bar	"	" " "		
7	Skate Wheel Conveyors	Unidirectional Skate Wheels	" " "		
8	" " "	Buffer Boards	" " "		
9	Roller Conveyors	" "	Seat Track Pallet Latch		
10	" "	" "	Flip-up Pallet Latch (DC-8)		
11	" "	Side Guide Rails	Pinlock in Rail w/ Special Pallet		
12	" "	" " "	Integral Latches Manually Actuated		
13	" "	" " "	Integral Latches Power Actuated		
14	" " w/ Portable Winch	" " "	" " " "		
15	" " w/ Integral Winch	" " "	" " " "	6	
16	Powered Roller Conveyors	" " "	" " " "	6	6
17	Full Width Conveyor	Buffer Boards	Automatic Overhead Cargo Net	6	6

Figure 8. Sample Automation Index Calculations

FUNCTION	Load							Re-strain				Release				Off Load							
	Pre-Position Cargo Mover	Attach Cargo Mover	Activate Cargo Mover	Move Cargo	Guide Cargo	Stop Cargo	Disconnect Cargo Mover	Pre-Position Restraint	Attach Restraint	Tighten Restraint	Lock Restraint	Unlock Restraint	Loosen Restraint	Disengage Restraint	Stow Restraint	Attach Cargo Mover	Activate Cargo Mover	Move Cargo	Guide Cargo	Stop Cargo	Disconnect Cargo Mover	[illegible] Cargo Mover	AUTOMATION INDEX
iown Rings																							0
ickle											6												6
											6		6										12
								6			6		6										18
				3				6			6		6					3					24
				5				6			6		6					5					28
				3	3	1		6			6		6					3	3	1			32
				3	4	1		6			6		6					3	4	1			34
atch				3	4	1				6	6		6	6				3	4	1			40
ı (DC-8)				3	4	1		6	6	6			6	6	6			3	4	1			52
Special				3	4	1		6	6	6			6	6	6			3	4	1			52
nually				3	4	3		6	6	6			6	6	6			3	4	1			54
wer				3	4	3		6	6	6	5	5	6	6	6			3	4	1			64
"				5	6	3		6	6	6	5	5	6	6	6			5	6	1			72
"	6			5	6	3		6	6	6	5	5	6	6	6			5	6	1		6	84
"	6	6		5	6	5	6	6	6	6	5	5	6	6	6	6		5	6	1	6	6	110
Cargo Net	6	6		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	1	6	6	121

B

System 8 — Automation Index = 34

This system is exactly like system 7 except that buffer boards are added, which relieves man of any decision for the guidance of cargo and therefore increases the automation rating 2 points for the system.

System 9 — Automation Index = 40

This system has the same degree of automation in the movement cycle as systems 7 and 8. However, the automation is provided by wide rollers. The increase in the automation index is caused by the restraint method. This system employs special rigid pallets to which the cargo is secured by nets, prior to loading. The latch is a clip-on type which attaches into a seat track installed in the aircraft floor (see Figure 9). Figure 10 shows this latch being used in an early model DC-8. The latch is installed after a pallet is in place, and it restrains that pallet plus the edge of the next pallet. Lifting the ring, shown in Figure 9, with the thumb, as shown in Figure 10, raises a detent which allows the fitting to be installed into a seat track. Release of the ring locks the fitting in place. The function of attaching the restraint is accomplished manually. The locking and tightening functions are performed simultaneously with the attaching function and are assigned values of 6. The loosening and disengaging functions are performed simultaneously with the unlocking function and are assigned values of 6.

System 10 — Automation Index = 52

This system is the same as system 9 except that buffer boards are added for guidance of cargo and integrally mounted flip-up latches are used for restraint. Figures 11, 12, and 13 show a model of this latch in the latching sequence. Figure 11 shows the latch stowed flush in the floor. Figure 12 shows the latch partially positioned. Figure 13 shows the latch in position to provide restraint for one edge of the preceding pallet as well as one edge of the next pallet.

The latch is integral with the floor, and therefore the functions of prepositioning and stowing restraint are assigned values of 6. The functions of attaching and tightening restraint are performed simultaneously with the locking of restraint and are assigned values of 6. The corresponding functions for the unloading cycle are also assigned values of 6.

System 11 — Automation Index = 52

This system uses rollers for movement of a special rigid pallet. Restraint is accomplished by side guide rails and a pin lock. The pallet has holes along the edges to accept the pins. Figure 14 shows the pin lock in the open position. The pallet is moved manually into the correct position and the pin is inserted. The pin is shown in the engaged position in Figure 15. The values assigned to functions are identical to those of system 10.

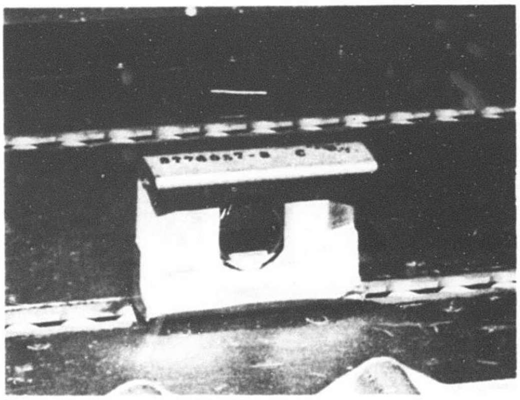


Figure 9. Pallet Restraint Device

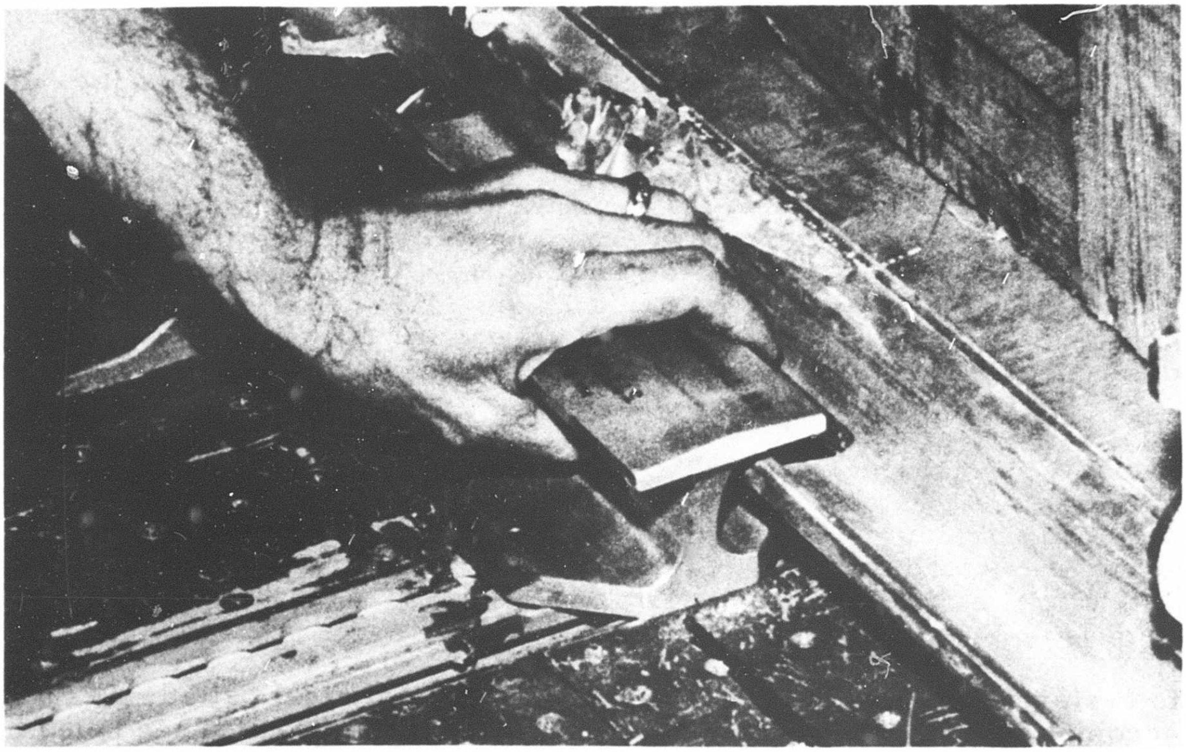


Figure 10. Installing Pallet Restraint Device

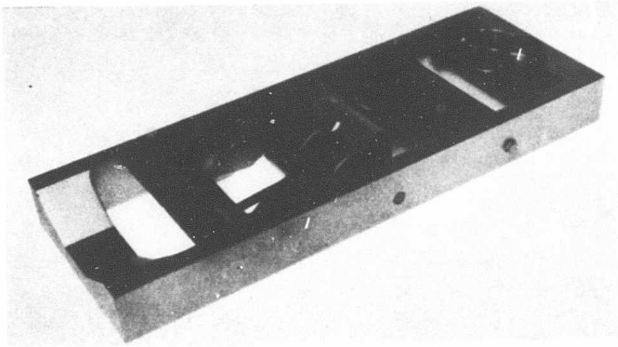


Figure 11. Flip-Up Latch, Retracted

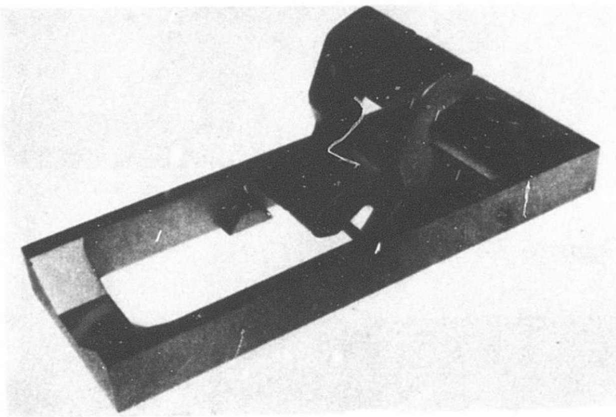


Figure 12. Flip-Up Latch, Partially Positioned

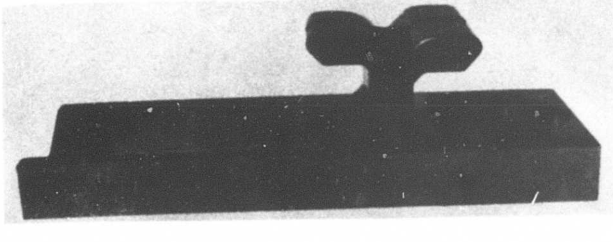


Figure 13. Flip-Up Latch, Restraint Position

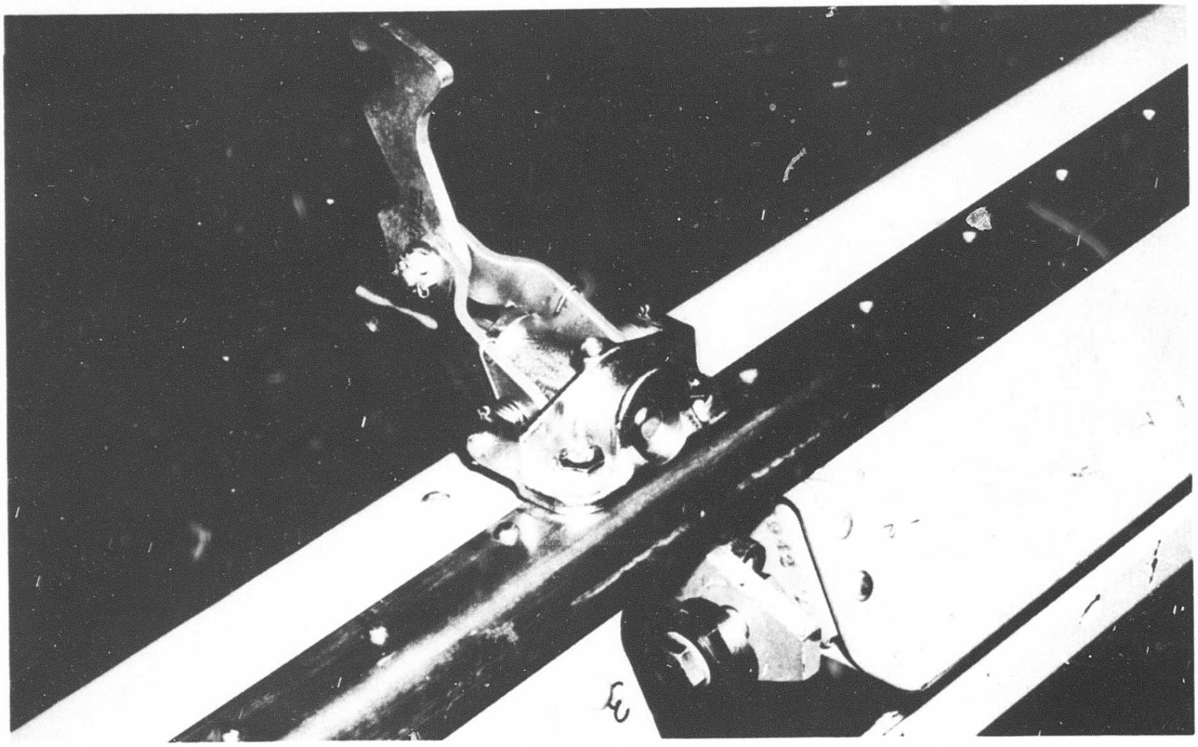


Figure 14. Pinlock Latch, Open Position

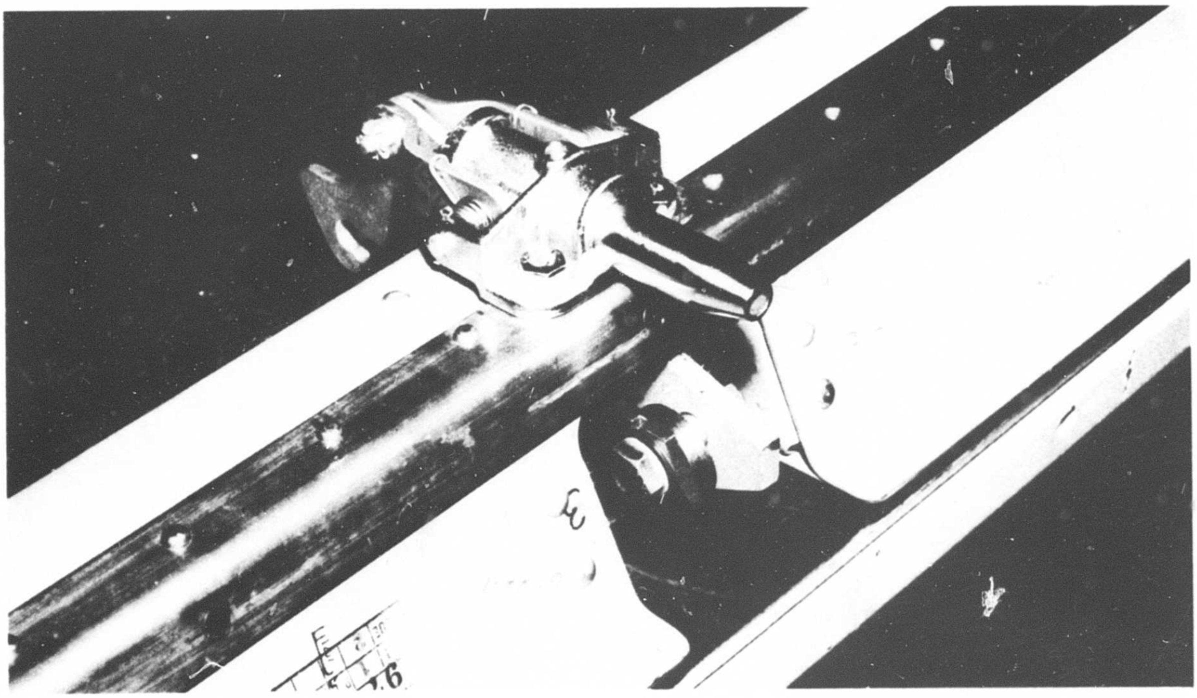


Figure 15. Pinlock Latch, Closed Position

This system has the same amount of automation as system 10. The effectiveness of the two systems will be considerably different. Also to be considered is the fact that system 11 is readily adapted to airdrop. System 10 is incompatible with airdrop. Although latching is by a different method, both systems have the same automation index.

System 12 – Automation Index = 54

This system is the typical 463L system as found in C-133 or C-130 aircraft. The system uses rollers and guide rails for movement. Latches provide forward and aft restraint,and the guide rail provides lateral and vertical restraint. A stop is provided at the forward end of the aircraft to help position pallets. The values assigned to the restraint functions are identical to those of systems 10 and 11. The "stop" function is assigned a value of 3 because the man loading the pallet must position it correctly to accept the latches. The "stop" function for the unloading cycle is identical to that for system 11.

System 13 – Automation Index = 64

This system is identical to system 12 except that power has been provided in the latching operation, which increases the automation. The functions of "lock" and "unlock restraint" are assigned values of 5 because power has been added, but man provides the decision.

System 14 – Automation Index = 72

This system is identical to system 13, but a portable winch has been added to aid in cargo movement. The winch must be attached to tiedown rings on the cargo floor prior to use. The winch increases the automation rating of the function "move cargo" to 5 for both the load and unload cycles.

System 15 – Automation Index = 84

This system is the same as system 14 except that the winch is integrally mounted. The functions of pre-positioning cargo mover and stowing cargo mover are both assigned values of 6.

System 16 – Automation Index = 110

This system is the same as system 13 except that powered rollers are used for cargo movement. To achieve an index this high, it is necessary to assume that ground equipment compatible with the aircraft system is available. The function "attach cargo mover" is assigned a value of 6 because pallets are brought into contact with the power rollers by the action of the ground loader. The function "disconnect cargo mover" is assigned a rating of 6 because the pallets are always in contact with the rollers (cargo mover). The "stop cargo" function is assigned a value of 5 because the system does all the work.

System 17 – Automation Index = 121

This system is similar to system 16, but the total loading and restraining sequence is accomplished by pushing a button. The off-load cycle automatically starts with the opening of the cargo doors. All functions are assigned ratings of 6 except the functions "activate cargo mover" which is completely manual (0 rating) and "stop cargo" which is assigned a rating of 1 because the ground equipment operator must stop the rollers when the cargo is out of the aircraft.

EFFECTIVENESS

INTRODUCTION

The preceding chapter discussed means of measuring the degree of automation of a given cargo handling system. The fact that a cargo handling system is highly automated does not necessarily mean that the system is more effective.

The purpose of this part of the study is to develop a method of determining the returns (measured in effectiveness units) from automating cargo handling functions within Army aircraft.

Both quantitative and qualitative factors must be considered in evaluating the effectiveness of an automated cargo handling system. Most of the quantitative factors may be integrated in a comprehensive effectiveness measure. This effectiveness results from the interaction of many elements within a given evaluation framework. Most of the quantitative factors which cannot be integrated into a comprehensive effectiveness measure may be tied together in the cost analysis. Directly or indirectly, all quantitative effectiveness factors are inputs to the cost analysis.

Most qualitative factors cannot be realistically integrated into either the effectiveness or the cost analysis and must stand alone as "other considerations." This in no way implies that they are unimportant. At a minimum, the qualitative factors serve to differentiate between systems having similar quantitative effectiveness and/or cost ratings. In some cases, qualitative considerations may even override quantitative considerations.

This study deals in a specific area (automation). The effects of automating cargo handling must be isolated from the effects of variations in a multitude of other delivery system parameters whenever possible. It is relatively simple to examine the effect of automating cargo handling within Army aircraft on any individual effectiveness parameter (e.g., manpower, loading time, etc.) for a defined aircraft cargo load. It is difficult to integrate these effects in a realistic manner so that the influence of each parameter on total delivery system performance may be evaluated in an operationally realistic manner.

The following sections of this chapter will discuss:

1. Factors determined by the cargo handling system.

2. Factors affecting the evaluation of cargo handling systems.

3. Qualitative effectiveness factors.

4. The general approach to integrating the diverse effectiveness factors to obtain a comprehensive measure of effectiveness.

5. Cargo dependent considerations.

6. The calculation of cargo system effectiveness.

FACTORS DETERMINED BY THE CARGO HANDLING SYSTEM

There are basically six factors directly determined by the cargo handling system:

1. Time — to load, restrain, release restraint, and unload a specified cargo load.

2. Payload degradation — due to the cargo handling system weight.

3. Aircraft availability — as affected by the cargo handling system reliability and maintainability.

4. Operating manpower — to handle the cargo.

5. Maintenance manpower — to maintain the cargo handling system.

6. Maintenance materials — required by the cargo handling system.

The first three factors directly affect the productivity of the total delivery system. The last three affect, primarily, the cost of operating the delivery system and will be discussed in the cost section of this report.

Generally speaking, adding a cargo handling system to an aircraft can reduce the aircraft availability and does reduce the useful payload of the aircraft. Counteracting these detrimental effects is the increased delivery system efficiency which results from reducing the cargo handling time.

Aircraft availability directly affects system producitivity, independent of any mission parameters. If 5 percent of the aircraft on hand are down for cargo handling system maintenance, overall delivery system productivity is reduced 5 percent, independent of the mission radius or the weight of each aircraft cargo load.

The effect of payload degradation due to the cargo handling system weight depends on the mission radius and the weight of the aircraft cargo load.

For example, assume that an aircraft without any cargo handling system has a payload of 10,000 pounds at a 100-nautical-mile radius and a payload of 5000 pounds at a 250-nautical-mile radius. The addition of a 2500-pound cargo handling system degrades the maximum useful payload by 25 percent at 100 nautical miles and by 50 percent at 250 nautical miles. If the aircraft is always loaded to capacity, one-third more aircraft will be required for a given 100-nautical-mile mission and 100 percent more aircraft will be required for a 250-nautical-mile mission, unless the payload degradation is offset by savings in cargo handling time. On the other hand, there will be no payload degradation penalty at either radius if the aircraft carries a volume limited 5000-pound payload.

While payload degradation directly detracts from delivery system productivity, the impact of cargo handling time savings depends on the mission flight time. Given a fixed mission radius, the round-trip cycle time decreases as the cargo handling time decreases, and an aircraft can fly more cycles in a given time period. Assume, for example, round-trip cycle times of 100 minutes and 180 minutes, 60 minutes of which is cargo handling time in each case. Decreasing the cargo handling time by 50 percent in each case results in 30-percent and 16.7-percent reductions in the total cycle time, respectively. The difference is due to the longer mission radius of the latter.

Generally speaking, as the mission radius increases, payload degradation has an increasingly detrimental effect, and savings in cargo handling time are less important.

Losses due to enemy fire while airborne or on the ground depend on a myriad of factors. The most important of these are: flight profile, the aircraft vulnerable area, type and intensity of enemy fire, dynamic engagement trigonometry, number of aircraft in the formation, number of times exposed, and time of exposure. Only the exposure time and the number of times exposed are affected by automating the cargo handling system. Three types of aircraft losses must be considered. There are losses due to

1. Accidents not involving enemy fire.

2. Enemy fire while the aircraft is airborne.

3. Enemy fire while the aircraft is on the ground.

Automating cargo handling within Army aircraft influences vulnerability in two counteracting ways. The weight of the cargo handling system decreases useful aircraft payload, thereby increasing the number of cycles necessary to deliver a fixed cargo quantity. Flying more cycles increases the accident losses and may increase the losses to enemy fire by increasing the number of times exposed to enemy fire. If automating cargo handling functions decreases the cargo handling time in the forward area, exposure time on the ground per cycle decreases, thereby decreasing this type of aircraft loss to enemy fire per cycle.

Payload degradation due to the weight of the cargo handling system and increased efficiency due to reduced cargo handling time are the primary influences of the cargo handling system. As the cargo handling system is a small part of the total delivery system, any effects of the cargo handling system on total delivery system performance will be small. To meaningfully measure these effects necessitates a number of carefully structured assumptions about the makeup of the aircraft cargo loads and accurate data development.

FACTORS AFFECTING THE EVALUATION OF CARGO HANDLING SYSTEMS

Three sets of parameters contribute to the operational framework for the evaluation: mission parameters, aircraft parameters, and cargo parameters.

Mission parameters include: radius, threat environment, terrain, delivery mode (airland or airdrop), time available, cargo to be delivered, unit supported, retrograde cargo quantity and composition, and type aircraft flown.

Aircraft parameters include: aircraft model, payload versus radius capability, dimensions, airfield requirements, takeoff time, flight times, accident rate, weight and balance system, cargo handling system, fuel consumption, fuel capacity, fueling rate, and vulnerability to enemy fire.

Cargo parameters, affecting primarily the analysis of weight per aircraft load and the cargo handling times, include: type cargo (pallets, bulk, POL, vehicles, personnel, or mixed cargo), description (weight, dimensions and special handling problems) of the items making up each unit aircraft load, total quantity of cargo to be delivered, and composition of the total cargo quantity.

QUALITATIVE EFFECTIVENESS FACTORS

Some effectiveness factors are primarily qualitative. The fact that these factors do not lend themselves to quantitative analysis does not mean that they are unimportant. As a minimum, they serve to differentiate between systems with similar quantitative effectiveness and cost ratings. A cargo handling system may rate high quantitatively but may be unsuitable because of qualitative factors, and vice versa.

The proficiency required of the cargo handling personnel is one such qualitative factor. Phrased differently, how well does the system perform when the only man familiar with the system is the aircraft crew chief? This criterion is especially important when operating in the forward area.

The degree of compatibility of the system with airdrop delivery is another qualitative factor. If restraint release is a slow process, it must be

initiated up to 10 minutes before the drop. This endangers operating personnel. Slow extraction affects drop accuracy and aircraft exposure time to enemy fire at a vulnerable altitude. Very slow extraction could even place the aircraft beyond its center of gravity limits. At a minimum, some type of side-guidance and friction-reducing device on the floor of the aircraft is required for airdrop.

The time, men, and materials required to prepare loads prior to loading may affect response time to an emergency request, airfield or storage area saturation, or may severely impede loading return cargo in the forward area. Another qualitative factor having similar ramifications is the time required to convert the cargo handling system from carrying one type of cargo to carrying a different type cargo, e.g., from pallets to vehicles.

Some forward area cargo handling systems are more compatible with ground handling equipment and surface transportation vehicles; some are more compatible with the form of the cargo as it is unloaded from the strategic aircraft used in deployment from CONUS.

The overall reliability and maintainability of the cargo handling systems may be estimated in a quantitative manner. How seriously the delivery system performance is degraded if the cargo handling system fails is an influential qualitative factor. Considerations in this area include expected types of failures, system performance after each type of failure has taken place, and time required to return the delivery system to operational status after a failure.

GENERAL APPROACH TO INTEGRATING QUANTITATIVE EFFECTIVENESS FACTORS

One particular cargo handling system may rate high in some effectiveness factors but low in others. Due to the large number of factors and possible effectiveness measures involved in evaluating automation, some integration of the effectiveness factors is required. Measuring the effectiveness of the system by system productivity is a generally accepted and applicable means of integrating a number of diverse elements in a problem such as this.

The analysis will measure the variable effectiveness and variable cost resulting from meeting a fixed operational requirement with a given cargo handling system in a given aircraft.

With cost a variable, only one of the three basic effectiveness parameters (number of aircraft, total time, and total cargo quantity) may be variable; otherwise, no defined answer is possible without the use of undesirable ratios. The selection of one of the three basic effectiveness parameters as the variable depends upon the desired form of the effectiveness measure, such as

1. The number of aircraft required to meet a fixed overall requirement (delivery of a fixed quantity of cargo within a fixed time period).

2. The time required to deliver a fixed quantity of cargo, given a fixed number of aircraft.

3. The quantity of cargo which a given number of aircraft can deliver in a fixed time period.

The three approaches are similar, but are simply different manipulations of the three basic effectiveness parameters. The variable aircraft approach has several advantages in light of the overall analysis. Cost has greater meaning in an absolute sense when it is the cost of meeting a fixed requirement (delivering a fixed quantity of cargo in a fixed time period) with a particular cargo handling system in an aircraft. Corresponding to this cost is an absolute quantity which measures the effectiveness of the cargo handling system, i.e., the number of aircraft required to meet the fixed requirement of delivering a fixed quantity of cargo in a fixed time period.

The objective is to obtain as pure a measure as possible of the return (positive or negative) from automating cargo handling within Army aircraft. The variable number of aircraft approaches is operationally realistic and best solves the problem.

More or fewer aircraft may be required with a particular cargo handling system when an integral three-point automated weight and balance system is added to the aircraft, depending on whether payload degradation or decreased cycle time is the dominant factor.

CARGO DEPENDENT CONSIDERATIONS

The previous discussion showed that it is advantageous to work with a fixed requirement (i.e., specific tonnage of cargo to be transported in a fixed time) and to determine the number of aircraft required to satisfy the requirement. The narrow scope of the problem precludes using generalized loading times and cargo parameters. For this reason, a deterministic approach was selected.

Two factors dictate the requirement to consider individual aircraft loads. These are the cargo handling time and the reduction of aircraft payload due to the weight of the cargo handling system. The method of making up aircraft loads must be capable of evaluating the effect of cargo handling system weight, permit accurate time evaluations, and appreciate the operational aspects of the problem. Each of the three factors is best understood if investigated separately.

Operational Realism in Cargo Load Composition

Within the scope of the study it is not possible to consider all of the different cargo loads which may be carried in Army aircraft. Two methods of composing aircraft loads were considered. A decision was required on whether to load mixed loads (loads with more than one type of cargo; i.e., vehicles and pallets, vehicles and POL, etc.) or separate loads (only one type of cargo per load), or both.

In actual Army operations some loads carried by Army aircraft will be mixed loads. Any conclusion drawn for pallets is valid for pallets in general. Any conclusion drawn for one mixed load is valid for the specific cargo composition of that load, and not for other mixed loads having different cargo compositions. With mixed loads there exists the possibility of unfair evaluation of a system because of the very makeup of the mixed loads. Separate loads, on the other hand, will permit accurate relative evaluation of various cargo handling systems but will lack somewhat in operational realism. No single answer to the conflict between operational realism and accuracy of the analysis is believed to exist. Therefore, to evaluate more accurately the effectiveness of various cargo handling systems, separate loads will be used for the bulk of the analysis, but several mixed loads will be included in each system evaluation for operational realism.

Cargo Handling Time

Cargo handling time has two major effects on delivery system effectiveness. For the short radius missions performed by Army aircraft, the cargo handling time is a significant portion of the mission cycle time. If cargo handling time is reduced, the total system effectiveness increases because each aircraft is more productive. Aircraft vulnerability is sensitive to cargo handling time at the off-load site. The loss of aircraft due to enemy fire is a function of the exposure time on the ground at the off-load site, as well as the number of times exposed, if the off-load site is a vulnerable area.

The cargo handling times must be analyzed for defined aircraft loads. Any evaluation which generalizes the cargo handling time will result in questionable conclusions. Two approaches are possible to determine loading time. The first would require calculation of the loading time, for each piece of cargo, for each cargo handling system. These data would then be used with a computer load planning program, which plans the most efficient manner to load a large amount of cargo. If the computer is also used to calculate the cargo handling times, it must be programmed to recognize the effect of loading sequence on cargo handling time for all possible cargo combinations. The unnecessary complications do not add to the evaluation of automation of cargo handling inside Army aircraft.

A second approach to the problem is to set up, for each aircraft, specifically defined loads which will be standard for the evaluation of any system. This

allows the hand calculation of cargo handling times. Times are accurate and each system is evaluated with the same loads.

The first approach will produce reasonably accurate cargo handling times, but the amount of data which must be put into the computer is prohibitive. The second approach is as accurate as the first, but does not evaluate all possible combinations or pieces of cargo. It uses frequently carried and representative loads for the evaluation. The objective of the study is to evaluate the automation of cargo handling inside Army aircraft, and not to optimize the loading process for large quantities of cargo. The second approach was adopted for ease and accuracy of calculations.

Cargo Handling System Weight

As previously stated, the evaluation must consider the weight penalty imposed on the aircraft by the cargo handling system. The determination of the makeup of the specific loads used in the evaluation is basically a problem of picking the method which best assesses the penalty of cargo handling system weight.

The assumptions made that every aircraft is grossed out whenever the aircraft is not volume limited and that all of the cargo handling system weight must be subtracted from payload are conservative. It is unlikely that it will be possible to utilize all of the available payload with every type of cargo in every aircraft, especially in the case of vehicles.

CALCULATION OF CARGO HANDLING SYSTEM EFFECTIVENESS

The cargo handling system effectiveness, measured by the number of aircraft required to meet a given requirement, is calculated by type of aircraft load because the cargo handling times depend on the specific cargo load analyzed. This is then summed to obtain the number of aircraft required by type of cargo. Further summation yields the cargo handling system effectiveness for the total mission cargo, including more than one type of cargo and/or mixed load(s).

In general, the initial number of operating aircraft A_{IY} required to transport cargo of type Y is:

$$A_{IY} = \sum A_{IYN} \tag{2}$$

The number of operating plus unavailable aircraft follows:

$$A_{PY} = P \cdot A_{IY} \tag{3}$$

where P is the inverse of the delivery system availability and A_{IYN} is the initial number of aircraft required to transport aircraft load type N of cargo type Y. There may be any number of different types of load configuration (N) of cargo type Y. For example, Y = 1 may represent palletized cargo and N = 1 pallets of rations, N = 2 pallets of ammunition; Y = 2 may represent vehicular cargo with N = 3, 4, and 5 representing three different vehicle loads.

As aircraft losses are small and nearly linear, an average number of operating aircraft may be used in the calculations:

$$A_{IYN} = A_{AYN} + \frac{A_{LYN}}{2} \quad (4)$$

where

A_{AYN} = average number of operating aircraft carrying load type N of cargo type Y over time period T_T.

A_{LYN} = total aircraft lost (defined as nonproductive during time period T_T) to accidents and enemy fire during time period T_T while carrying load type N of cargo type Y.

The average number of aircraft required depends on the number of aircraft loads of load type N, the cycle time T_{CYN}, and the total time T_T during which all cargo deliveries must be completed.

Cargo lost when aircraft are lost (for the mission time period T_T) is negligible because the aircraft losses are generally small, and the loss of an aircraft does not necessarily mean that the cargo is lost. The major effect of an aircraft lost on total system effectiveness is the loss of the use of that aircraft on future cycles. Cargo lost due to impact damage or landing in an enemy area after airdrop is not to be considered in this study.

Assuming that cargo lost is negligible,

$$A_{AYN} = \frac{C_{TYN}}{C_{LYN}} \cdot \frac{T_{CYN}}{T_T \cdot 60} \quad (5)$$

where

C_{LYN} = cargo load per aircraft per flight (load type N of cargo type Y).

C_{TYN} = total quantity of cargo (load type N of cargo type Y).

T_T = total time available to complete all cargo deliveries.

T_{CYN} = total single aircraft cycle time (one cycle includes two flights, primary and retrograde).

The cycle time T_{CYN} is the sum of the flight time per cycle and the ground time per cycle.

$$T_{CYN} = T_1+T_2+T_3+T_4+T_5+T_6+ (1 - K) (T_7) + T_8 \ldots +T_{17} \qquad (6)$$

T_4, T_5, T_6, T_{12}, T_{13}, T_{14}, and T_{17} are flight times; the other T's are cargo handling times. All are defined at the beginning of this report. The cumulative flight hours (T_{FYN}) are given by:

$$T_{FYN} = \frac{C_{TYN}}{C_{LYN} \cdot 60} \cdot (T_4+T_5+T_6+T_{12}+T_{13}+T_{14}+K(T_8)) \qquad (7)$$

The cumulative ground hours (T_{GYN}) are given by:

$$T_{GYN} = \frac{C_{TYN}}{C_{LYN} \cdot 60} \cdot (T_1+T_2+T_3+ (1 - K) (T_7+T_8) + T_9 + T_{10} + T_{11} + T_{15} + T_{16} + T_{17} \qquad (8)$$

The "K" factor accounts for the cargo handling functions performed while the aircraft is in flight on airdrop missions. While there is a defined time to release restraint T_7 on airdrop missions, this cargo handling function is performed while descending to airdrop altitude and is included in T_6. The time to unload cargo T_8 is flying time for an airdrop mission, whereas both T_7 and T_8 are ground times for an airland mission. K = 1 for airdrop. K = 0 for airland. The retrograde cargo handling times are, of course, zero for airdop missions.

A_{LYN} is composed of

1. Accidental losses (some repairable, but assumed lost for the duration of the mission).

2. Vulnerability losses to enemy fire (some repairable).

The first is a function of flight hours; the latter is a function of exposure time with given tactics and enemy fire.

In general,

$$A_{LYN} = \frac{C_{TYN}}{C_{LYN}} \left(V_1 + V_2\right) \tag{9}$$

where

V_1 = accident rate per single aircraft per cycle.

V_2 = aircraft downed per single aircraft per cycle.

$\frac{C_{TYN}}{C_{LYN}}$ = number of single aircraft cycles carrying load type N of cargo type Y.

The initial number of aircraft required is calculated for each type of aircraft load N by using equation 10.

$$A_{IYN} = \left(\frac{C_{TYN}}{C_{LYN}} \cdot \frac{T_{CYN}}{T_T \cdot 60}\right) + \frac{1}{2}\left[V_1\left(\frac{C_{TYN}}{C_{LYN}}\right) + V_2\left(\frac{C_{TYN}}{C_{LYN}}\right)\right] \tag{10}$$

A_{IYN}, A_{LYN}, T_{FYN}, and T_{GYN} are calculated for each aircraft load type N of cargo type Y and are then summed for the cargo type Y.

$$A_{PY} = P \cdot A_{IY} \tag{3}$$

$$A_{IY} = \Sigma A_{IYN} \tag{2}$$

$$A_{LY} = \Sigma A_{LYN} \tag{11}$$

$$T_{FY} = \Sigma T_{FYN} \tag{12}$$

$$T_{GY} = \Sigma T_{GYN} \tag{13}$$

The above quantities are also inputs to the cost analysis.

The aircraft and hours for each cargo type Y are again summed to obtain values for the total mission cargo (C_T):

$$A_I = \Sigma A_{IY} \tag{14}$$

$$A_P = \Sigma A_{PY} \tag{15}$$

$$A_L = \Sigma A_{LY} \tag{16}$$

$$T_F = \Sigma T_{FY} \tag{17}$$

The comparison of any two cargo handling systems using the cost or effectiveness measures proposed in this report does not require any automation index. The effectiveness result is as valid as the input parameters used and is independent of the automation index. The automation index is only a measure of the degree of automation present in a particular cargo handling system and is used to provide a common horizontal axis value against which to plot the cost and effectiveness measures.

As the automation index (measure of the degree of automation) for a particular cargo handling system is different for each type of cargo, a composite automation index value is necessary in order to derive an expression for a cargo quantity made up of more than one type of cargo, even though all aircraft loads are of only one type of cargo.

The automation index for each type of cargo is weighted by the percent of the total cargo tonnage which is of that type, and a composite automation index value is obtained.

$$I = \sum \frac{I_Y \cdot C_{TY}}{C_T} \tag{1}$$

where

I = weighted composite automation index value valid only for one specifically composed total cargo quantity C_T.

C_T = total quantity of cargo of all types delivered in time T_T (including mixed loads).

C_{TY} = total quantity of cargo of type Y delivered in loads composed purely of one type cargo or of one specific mixed aircraft load.

The sequence of the effectiveness calculations is as follows:

1. Select the aircraft model and define whether the aircraft has an integral three-point automated weight and balance system.

2. Determine the net available payloads after the cargo handling systems have been added to the aircraft.

3. Define the mission delivery mode (airland or airdrop) and thereby the delivery mode factor ($K = 1$ for airdrop; $K = 0$ for airland).

4. Define the mission radius and combat environment.

5. Define the total quantity (C_T tons) of mission cargo and the composition of the cargo quantity by type of cargo Y (C_{TY} tons of cargo type Y). Each specific mixed aircraft cargo load should be considered a separate type of cargo (Y).

6. For each cargo type Y (C_{TY} tons), plan the specific aircraft loads of that type of cargo (N different type loads of cargo type Y) and the tons of each aircraft type load (C_{TYN} tons). The sum of the tons (ΣC_{TYN}) of each aircraft type load (N) of cargo type Y equals the total tons (C_{TY}) of cargo type Y. For example, if $Y = 1$ and $N = 1, 2, 3$, $C_{T1} = C_{T11} + C_{T12} + C_{T13}$. The tons of each aircraft type load (C_{TYN}) will depend on the weight of the cargo handling system installed in the aircraft.

7. Define the retrograde cargo load quantity as a percent of the outbound primary cargo and as the percentage composition of each retrograde aircraft load. For example, the retrograde cargo could equal 50 percent of the primary cargo weight, made up of 15-percent bulk cargo and 35-percent ambulatory and litter patients.

8. Define the general aircraft flight profile (speed and altitude).

9. Calculate the primary (outbound) mission flight times: the time to taxi, take off, and climb to cruise altitude (T_4 minutes); the time enroute at cruise altitude (T_5 minutes); and the time to either (1) descend, land, and taxi for the

airland delivery mode or (2) descend to airdrop altitude (but not to drop the cargo) for the airdrop delivery mode (T_6 minutes).

10. Calculate the retrograde (return) mission flight times: the time to either (1) taxi, take off and climb to cruise altitude or (2) climb from airdrop altitude to cruise altitude (T_{12} minutes); the time enroute at cruise altitude (T_{13} minutes); and the time to descend, land, and taxi (T_{14} minutes).

11. Calculate the refueling time (T_{17} minutes) per cycle (primary flight plus retrograde flight). Depending on the payload, airfield, and radius constraints, this refueling time per cycle might be viewed as (1) the time to add sufficient fuel to the aircraft for one cycle or (2) a portion of the time required to fuel the aircraft to capacity, allocated on the basis of the fuel burned on one cycle.

12. For the primary mission cargo, calculate the time to load (T_1 minutes), restrain (T_2 minutes), verify weight and balance (T_3 minutes), release restraint (T_7 minutes), and unload (T_8 minutes) for each defined aircraft type load (C_{LYN} tons) and cargo handling system. Note that with most cargo handling systems, the restraint begins while cargo is still being loaded. It is recommended that T_2 and T_8 be regarded as the additional time required to restrain the primary cargo after loading is complete and the additional unloading time after all restraint is released, respectively.

13. For the retrograde mission cargo, calculate the time to load (T_9 minutes), restrain (T_{10} minutes), verify weight and balance (T_{11} minutes), release restraint (T_{15} minutes), and unload (T_{16} minutes). The same overlap of restraint and loading exists as discussed above, and may be handled in the same manner.

14. Calculate "P," the reciprocal of the delivery system (aircraft plus cargo handling system) availability.

15. Define the accident losses per aircraft per cycle (V_1).

16. Define the losses to enemy fire per cycle (V_2) for the appropriate mission environment and evaluation case.

17. Define the percent (F) of the downed aircraft (A_{LYN}) that are a total loss.

18. Calculate T_{CYN} for each combination of aircraft, delivery mode, cargo handling system, and load type (equation 6).

19. Calculate T_{FYN} and T_{GYN} for each case and store the results for summing (equations 7 and 8).

20. Calculate the number of downed aircraft (A_{LYN}) for each case and store the results for summing (equation 9).

21. Calculate the initial number of operating aircraft (A_{IYN}) required in each case and store the results for summing (equation 10).

22. Calculate the cumulative flight hours (T_{FY}, the sum of the T_{FYN}) for each cargo type Y and store the results for further summation (equation 12).

23. Calculate the cumulative ground hours for each cargo type Y (T_{GY}, the sum of the T_{GYN}) and store the results (equation 13).

24. Calculate the initial number of operating aircraft required (A_{IY}, the sum of the A_{IYN}) and the aircraft downed (A_{LY}, the sum of the A_{LYN}) for each cargo type Y and store the results for further summation (equations 2 and 11).

25. Calculate A_{PY}, the initial number of operating and unavailable aircraft required for each cargo type, and store the results (equation 3).

26. Calculate A_P, A_I, A_L, T_F, and I for the total mission cargo quantity C_T (equations 15, 14, 16, 17, and 1, respectively).

The 7090/7094 computer was used to process the data in this project. Although the calculations involved were quite straightforward, the volume of calculations made hand calculations impractical. The computer also functioned as an economical typist, printing both the input and output data in orderly columns.

The computer program handles a variable quantity of data and performs calculations and summations at certain levels of data. There may be as many as 20 cargo handling systems under each aircraft and delivery mode, 10 cargos under each system, and 50 loads under each cargo type.

In calculating effectiveness, mixed loads are treated essentially the same as loads of only one type of cargo. The computer program recognizes no difference between mixed loads and loads of only one type of cargo. The difference is in the data development prior to the calculations.

COST METHODOLOGY

Costs are of primary importance in evaluating degrees of automation of cargo delivery systems within U. S. Army aircraft. Since the U. S. Army does have limited resources, a procedure for measuring the resource requirements of alternative delivery systems is required if the allocation of these resources is to be optimized. The costs of the various resources (personnel and materiel) expended in the introduction and continued operation of any system can be represented by their attendant dollar costs, thus providing one basis for comparing alternatives.

Cost will be a variable because the fixed cost case creates many problems and does not show the return from automating cargo handling within Army aircraft as clearly as does a variable cost approach. As the name implies, fixed cost forces the analyst to structure the effectiveness analysis so that the total cost remains fixed. Specifically, using fixed cost to evaluate automation would force the analyst to work only with a few combinations of aircraft, cargo, and total delivery time, which cost a fixed amount, and would not permit illustrative examination of the effectiveness achieved by a given cargo handling system in meeting a given requirement.

The objectives of the cost analysis are threefold:

1. Establish the best costing approach to evaluate the various cargo handling systems.

2. Develop a cost model which will quantify the cost of each delivery system, given the required input data.

3. Quantify the final cost outputs such that each cargo delivery system and its economic ramifications can be evaluated.

Several standard analytical costing concepts are employed in cost effectiveness analyses. These concepts have been developed and utilized by various levels of Department of Defense groups and aerospace system contractors.

<u>Total Force Cost</u> is the total cost associated with the larger operating organizations within the military complex; e.g., the General Purpose Forces, Strategic Offensive Forces, and Airlift/Sealift Forces. There are nine of these categories comprising the major military programs.

<u>Total Program Cost</u> of a particular system (or program) refers to its total "cradle-to-grave" cost (the cost of its entire life cycle). These program elements are the basic building blocks at the decision-making level of the programming process within the Department of Defense.

Total System Cost is the level of cost pertaining to a particular period within the life of a system and is normally referred to as the "n-year system cost" of that system.

Within the life of each system (or program), various assigned tasks and missions will be performed and will have certain costs allocated to them. To each mission (or task) can be assigned the particular cost of performing that mission, defined as Total Mission Cost.

By properly aggregating all the assigned missions and their attendant costs for any system over a period of n-years, its n-year total system cost can be determined. Expanding the operation of this system over its life cycle, one can accumulate all the relevant costs in the total program cost of that particular system. Integration of this total program cost with the costs of all other military programs performing the same function results in total force cost. These four costing concepts and the scope of aggregate cost can be illustrated with a cost cone, a concept embodying circles at each level to imply the general magnitude of one cost to another, as illustrated in Figure 16.

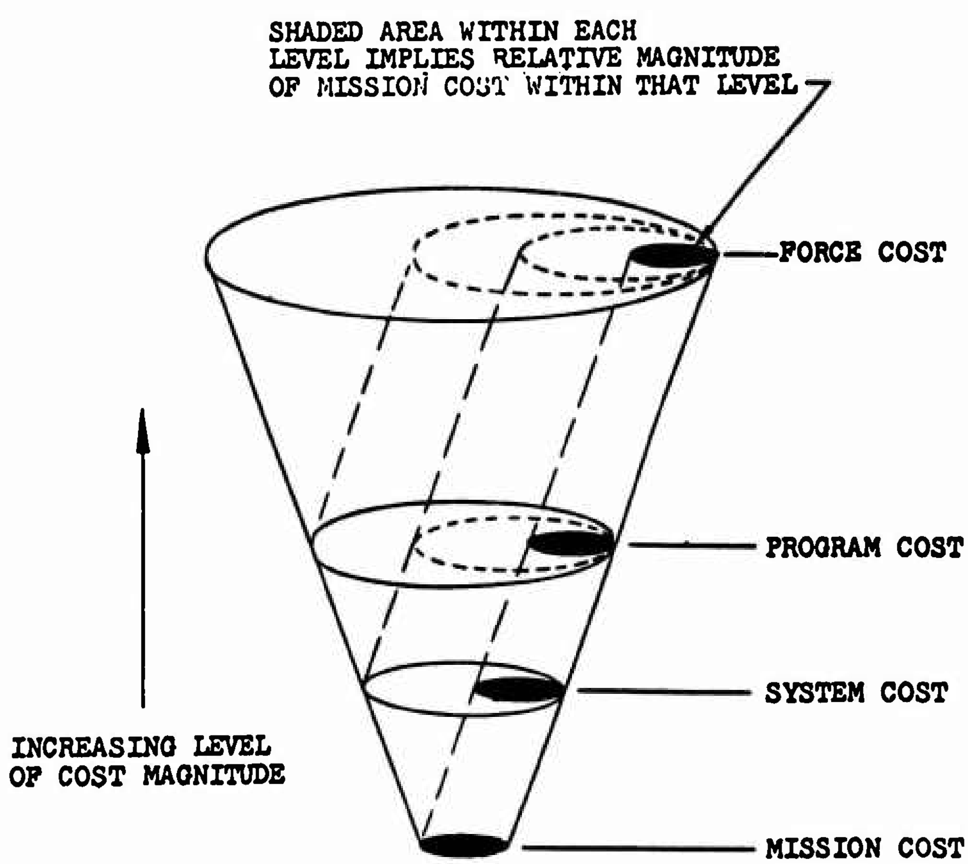


Figure 16. Cost Cone

Total system cost is normally the lowest level of cost considered when comparing the costs of competing systems. In the selection of the best approach to adequately describe the cost ramifications of automated cargo delivery systems, the intent was to choose that method (or level) of cost evaluation which would focus only on those costs peculiar to the cargo delivery system. The selected approach should eliminate those facets of cost which contribute little or nothing to the evaluation of automation of cargo delivery within U. S. Army-type aircraft.

Total mission cost was selected as the proper methodological level for cost evaluation.

Selection of total mission cost was influenced by the following factors:

1. It accounts for those measurable and pertinent factors directly attributable to the cargo delivery system as an operating unit (aircraft plus cargo handling system).

2. It is within the proper scale of operations: certain types of aircraft performing assigned missions (initial deployment and resupply) and irrespective of any "formal" military organization such as an aviation company or air assault division.

3. It is the lowest cost level that can be logically defined without losing the accuracy required to evaluate system automation adequately. Only at the mission cost level can the addition of an automated cargo handling system to an aircraft be properly evaluated. At the higher levels of the cost cone, the costs accrued by adding automated systems become insensitive in comparison to the many other costs (airfield facilities, equipment, administration, etc.).

As in the higher cost levels, the basic cost categories of research and development, initial investment, and operations are included in total mission cost. Research and development (R&D) represents the cost of bringing a new weapon system or capability to the point where it is ready for operational use. The investment category represents the costs beyond the development phase required to introduce a new capability into operational use. The operating costs are the recurring costs required to man, operate, and maintain that capability. Quite often the cost of operating a system (or subsystem) over its expected life is more important (and often much larger) than its investment cost. Operating costs can be crucial in the decision to produce and deploy one system as compared with another.

A mission cost model is developed to determine (based on inputs from the effectiveness analysis) the total mission cost of each cargo delivery system for a given mission. Basically each total mission cost will consist of three

primary cost elements: mission investment cost, mission operating cost, and mission loss cost. The logic flow of the total mission cost model is depicted in Figure 17. It is diagrammed in this manner to denote the various elements of costs and their relation to the total.

The inputs required (from the effectiveness analysis) to perform the cost analysis function are:

1. Type of mission.
2. Type of aircraft.
3. Type of cargo handling system.
4. Type and load of cargo.
5. Total flying time required by cargo type Y.
6. Total ground time required by cargo type Y.
7. Total number of operating days per mission and the length of the operating day.
8. The cargo delivery system availability factor.
9. The average number of operating aircraft required per mission by cargo type Y.
10. Total number of cargo delivery systems lost during the mission by cargo type Y.

Each cargo delivery system is composed of an aircraft and its cargo handling system. For this analysis, it is assumed that the R&D of each of the four aircraft has been written off and will not be charged to the mission. Each aircraft will be charged only its investment cost, herein defined as unit flyaway cost plus initial support cost. For those cargo handling systems requiring development, an additional cost increment will be included in its investment cost. The investment costs for both the aircraft and cargo handling system are utilized in total and are also prorated over their respective useful lives. The operating cost of each cargo delivery system is comprised of four factors: operating cost per flight hour, operating cost per ground hour, operating cost per operating day, and operating cost per ton (of cargo) loaded. This discrete breakdown is necessary because of the narrow scope of this particular study.

The underlying philosophy of this cost allocation hypothesis is as follows: the basic unit of time is the operating day during which the mission is performed. The operating day (for any cargo delivery system) is comprised

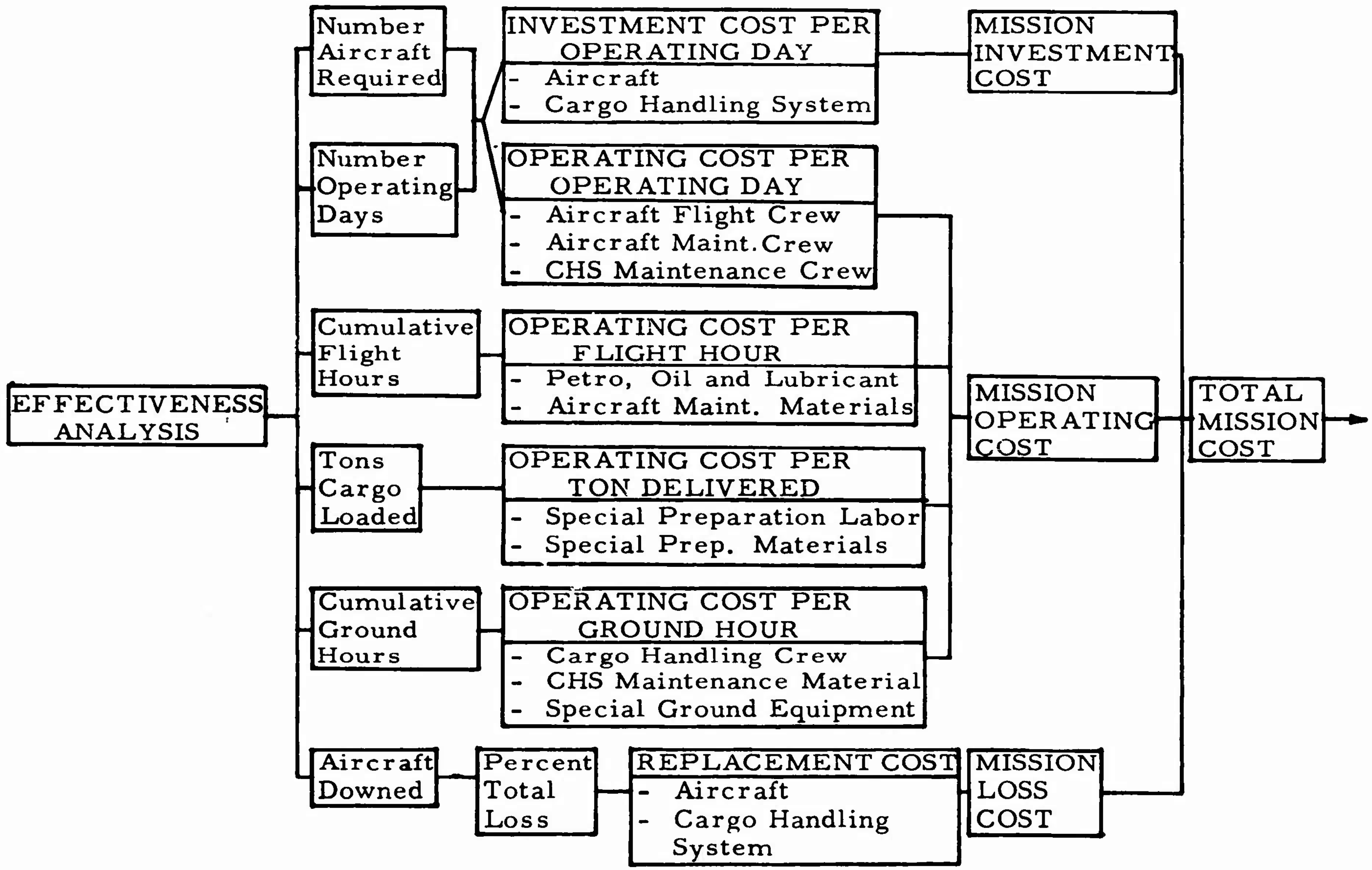


Figure 17. Logic Flow of Total Mission Cost Calculation Showing Inputs from Effectiveness Analysis

of flight time and ground time (Figure 18). During the ground time phase of the operating day, the cargo delivery system loads and discharges certain types and amounts of cargo, a function which consumes labor and materiel. This is true for all airland missions and for the loading phase of the airdrop missions. Since the cargo discharge time of the airdrop missions is relatively small, only the materiel cost is considered. During the in-flight portion of each mission, each aircraft is charged with its POL and materiel expenditures. Allocating the investment cost and personnel cost of the cargo delivery system over each operating day is similar to commercial business techniques, in which transportation modes plus their operating personnel are costed on a per-day basis, regardless of their utilization. In summary: each mission is charged a prorated cost of procuring the transportation required to perform the mission; to this is added the cost of the losses incurred during the execution of the mission and the operating costs, which are dependent on flight time, ground time, cargo loaded, and operating days; total mission cost results.

For any cargo type (Y), the mission cost of any cargo delivery system can be described by the following equation:

$$M_Y = I_{TY} + O_{TY} + L_{TY} \qquad (18)$$

where

M_Y = total mission cost for cargo type Y.

I_{TY} = total mission investment cost for cargo type Y.

O_{TY} = total mission operating cost for cargo type Y.

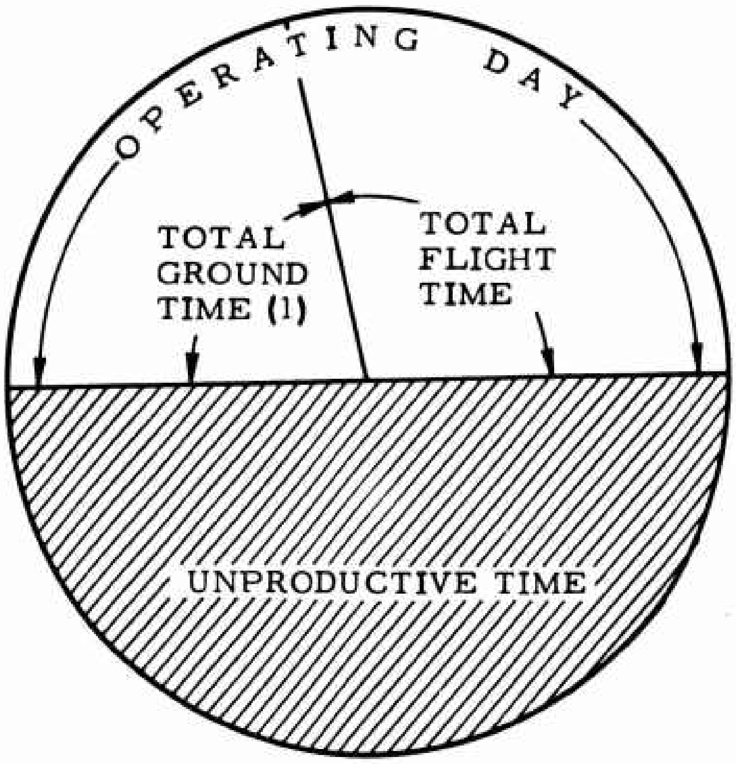
L_{TY} = total mission loss cost for cargo type Y.

The total mission investment cost is determined through the relationship between the amortized investment costs, number of operating days required, average number of cargo delivery systems required, and system availability, and can be expressed as

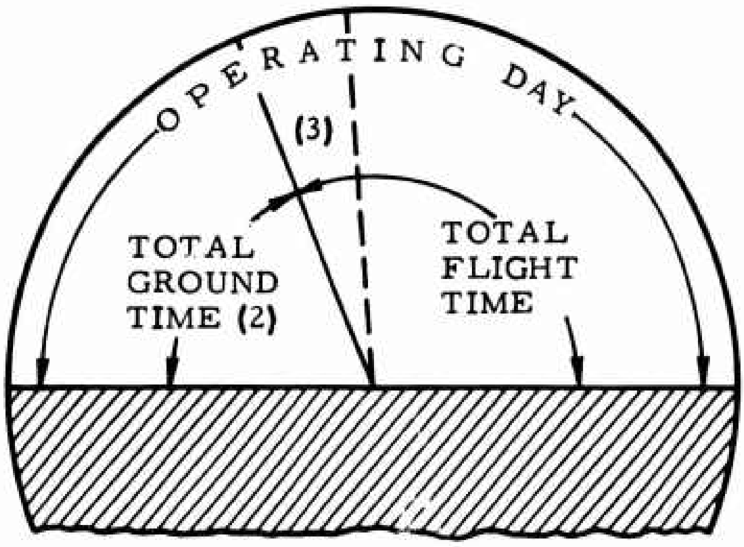
$$I_{TY} = (I_{ODA} + I_{ODC}) \left[(T_T/T_{OD})\,(A_{IY} - A_{LY}/2)\,(P)\right] \qquad (19)$$

where

I_{ODA} = amortized aircraft investment cost per operating day, comprised of the unit flyaway cost and unit initial support cost of each aircraft.



AIRLAND



AIRDROP

(1) All cargo loading and unloading performed in this period.

(2) All cargo loading performed in this period.

(3) Cargo discharged during this period of total flight time.

Figure 18. Operating-Day Concept for any 24-Hour Period

I_{ODC} = amortized cargo handling system investment cost per operating day, comprised of a unit research and development cost (if any), unit flyaway cost, and unit initial support cost.

$\left[(T_T/T_{OD})\ (A_{IY} - A_{LY}/2)\ (P)\right]$

= term denoting the number of aircraft-operating days required to perform the assigned mission by cargo type Y.

The total mission operating cost is comprised of four rate functions, as follows:

$$O_{TY} = \left[(O_{FH})(T_{FY})\right] + \left[(O_{OD})(T_T/T_{OD})(A_{IY} - A_{LY}/2)(P)\right] + \left[(O_{TL})(C_{TY})\right] + \left[(O_{GH})(T_{GY})\right] \tag{20}$$

where

O_{FH} = operating cost per flight hour: the sum of the aircraft POL cost/flight hour and the aircraft recurring parts cost/flight hour.

O_{OD} = operating cost per operating day: the sum of the daily costs of the flight crew, aircraft maintenance crew, and cargo handling system maintenance crew.

O_{TL} = operating cost per ton loaded: the sum of the cost of labor and materiel expended in the special cargo preparation required by some cargo handling systems.

O_{GH} = operating cost per ground hour: the sum of the cargo handling system recurring parts cost, the loading/unloading labor cost, the ancillary ground handling equipment cost; all of which are amortized per unit of ground-hour operation by cargo type Y.

The total mission loss cost represents the cost of replacing those cargo delivery systems lost in the performance of the designated mission. It is a function of the investment cost per cargo delivery system and the expected losses per mission.

$$L_{TY} = (A_{LY})(F)\ (I_D) \tag{21}$$

where

$(A_{LY})(F)$ = term defining the number of cargo delivery systems lost while delivering cargo type Y.

I_D = the unit investment cost per cargo delivery system; the sum of the aircraft unit investment cost (I_{DA}) and the cargo handling system unit investment cost (I_{DC}).

From the investment, operating, loss, and total mission costs for each cargo type Y, the appropriate costs may be determined for the total cargo quantity C_T by using the following equation:

$$I_T = \Sigma I_{TY} \tag{22}$$

$$O_T = \Sigma O_{TY} \tag{23}$$

$$L_T = \Sigma L_{TY} \tag{24}$$

$$M = \Sigma M_Y = \Sigma I_{TY} + \Sigma O_{TY} + \Sigma L_{TY} \tag{25}$$

Costs are first calculated by cargo type Y, then summed for the total mission cargo C_T for each combination of cargo handling system, aircraft, weight and balance system, and delivery mode.

To perform the cost analysis, the following sequence should be followed.

1. Select aircraft type.
2. Select cargo handling system type.
3. Input unit flyaway cost of aircraft (less any cargo handling system).
4. Input proper initial unit support factor to determine aircraft unit investment cost (I_{DA}).
5. Determine the useful combat life of the aircraft in operating days.
6. Amortize the unit aircraft investment cost over its expected useful life (I_{ODA}).

7. Input unit research and development cost of the cargo handling system (CHS).

8. Input unit flyaway cost of the CHS.

9. Input proper initial unit support factor for the CHS.

10. Derive the composite unit investment cost per CHS by summing 7, 8, and 9 (I_{DC}).

11. Determine the useful combat life of the CHS.

12. Amortize the unit CHS investment cost over its expected useful life (I_{ODC}).

13. Derive the cargo delivery system investment cost by summing 4 and 10 (I_D).

14. Input proper mission fuel consumption, based on delivery mode selected.

15. Determine the mission POL cost per flight hour, based on standard POL rates.

16. Input aircraft replenishment spares/parts cost per flight hour.

17. Derive the composite operating cost per flight hour by summing 15 and 16 (O_{FH}).

18. Input number (and types if possible) of personnel per flying crew.

19. Input number of maintenance personnel required per unit aircraft.

20. Determine the number of additional maintenance personnel required to maintain the CHS (on a per cargo delivery system basis).

21. Determine the pay and allowance cost per aircraft day (including flight pay where applicable), based upon the manpower requirements estimated in 18, 19, and 20 (O_{OD}).

22. Determine the cargo preparation cost per ton loaded for each combination of aircraft, CHS, delivery mode (airland or airdrop), cargo type, and load type (O_{TL}).

23. Determine the CHS replenishment parts cost per unit of operating ground time.

24. Determine the total unloading/loading labor cost per unit of operating ground time.

25. Determine the cost of any ancillary ground support equipment (if any) per unit of ground operating time.

26. Derive the composite operating cost per ground time by summing items 23, 24, and 25 (O_{GH}).

27. Store results of steps 6, 12, 13, 17, 21, 22, and 26 by cargo type Y for combination with outputs from the effectiveness analysis.

28. Calculate I_{TY}, O_{TY}, L_{TY}, and M_Y for each cargo type included in the composition of C_T (equations 19, 20, 21, and 18). Store the results for further summation.

29. Calculate I_T, O_T, L_T, and M for the total cargo quantity C_T (equations 22, 23, 24, and 25).

30. Repeat the entire calculation sequence for each cargo delivery system to be evaluated for all combinations of aircraft, weight and balance system, and delivery mode.

The task of structuring a cost model to describe adequately all of the complex interrelationships between subelements is a function of adequate historical field and test data, particularly in the area of various cargo handling systems. The limitations of any cost approach should be recognized when final decisions are made.

INTEGRATION OF EFFECTIVENESS AND COST

The techniques explained in the following paragraphs are designed to illustrate and aid in the analysis of

1. The absolute values of the cost and effectiveness measures as the degree of cargo handling system automation increases.

2. The relative changes in cost and effectiveness as the degree of automation increases.

3. The relationship between cost and effectiveness as the degree of automation increases.

These goals are achieved primarily by trend plots and percentage return plots that are plotted versus the automation index and the percentage increase in automation index, respectively. All graphical analysis is supported by tabular data. The position of the integration function in the overall flow of the analysis is shown in Figure 19. This figure will also serve to review the analysis before proceeding.

Figure 20 illustrates the general form of the trend analysis plots. None of the curves is cumulative because the graphs are intended to show absolute trends. Effectiveness is shown for both the total mission cargo and for each cargo type to aid in exploring causal relationships. Operating, investment, and loss costs are shown in addition to total mission cost for the same reason. In cases where the automation index is almost the same for all cargo handling systems, as in handling vehicles and men for the deployment mission, bar charts are used to achieve the same comparisons as trend plots.

Percentage return plots similar to those illustrated in Figure 21 show both the relative changes and the relationship between cost and effectiveness as the degree of cargo handling system automation increases. The percentage changes in effectiveness, cost, and automation index are all calculated by the following formula:

$$\% \text{ Change} = 100 \times \frac{\text{System "X" Value} - \text{Manual Value}}{\text{Manual Value}}$$

Percentage changes are tabulated for all missions, but are graphed only for the resupply missions where the spread of automation indexes permits.

In region A of Figure 21, effectiveness is increasing and cost decreasing. At the right of region A, cost is a minimum. In region B, effectiveness continues to increase while cost has passed its minimum point and is rising.

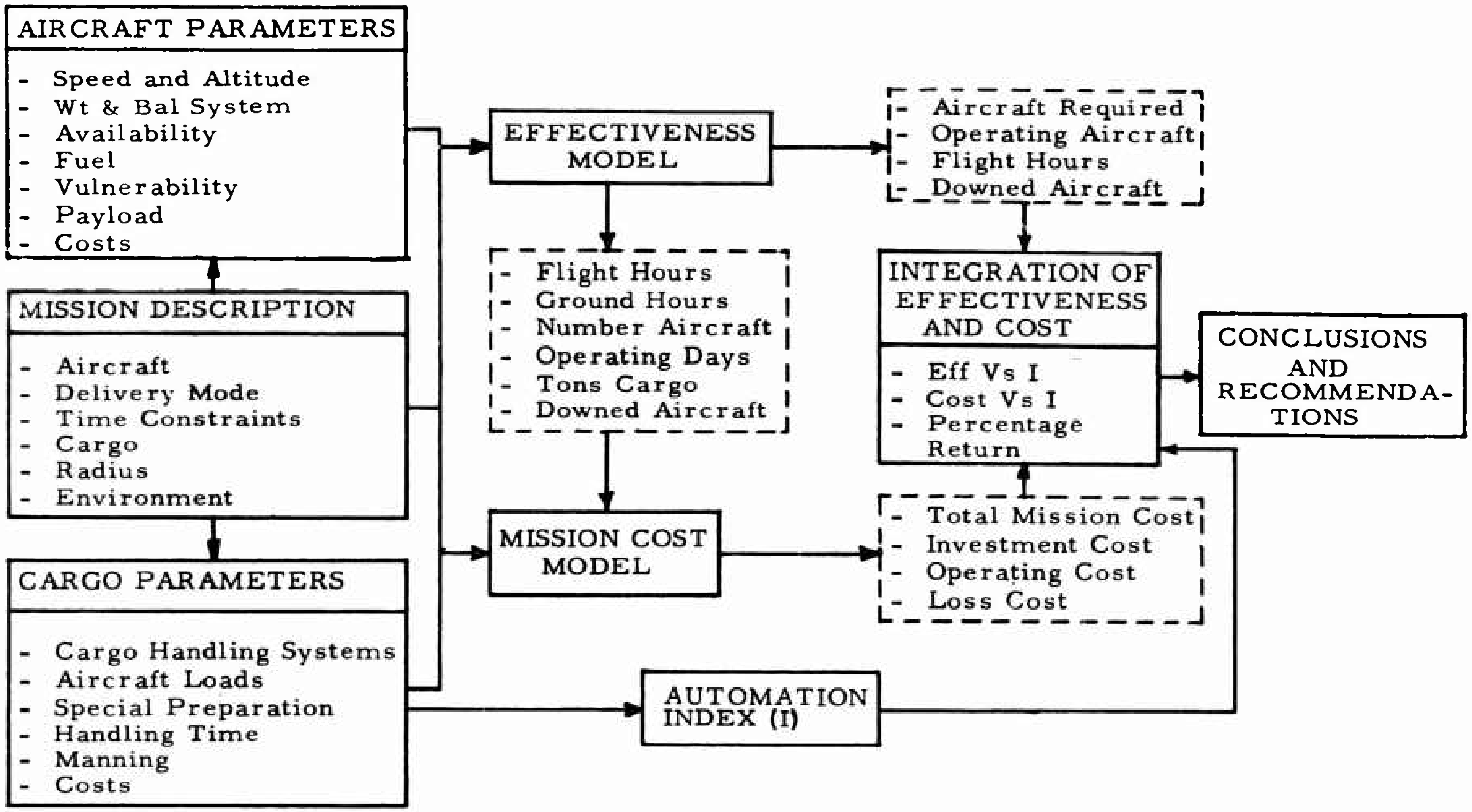


Figure 19. Overall Flow of Analysis

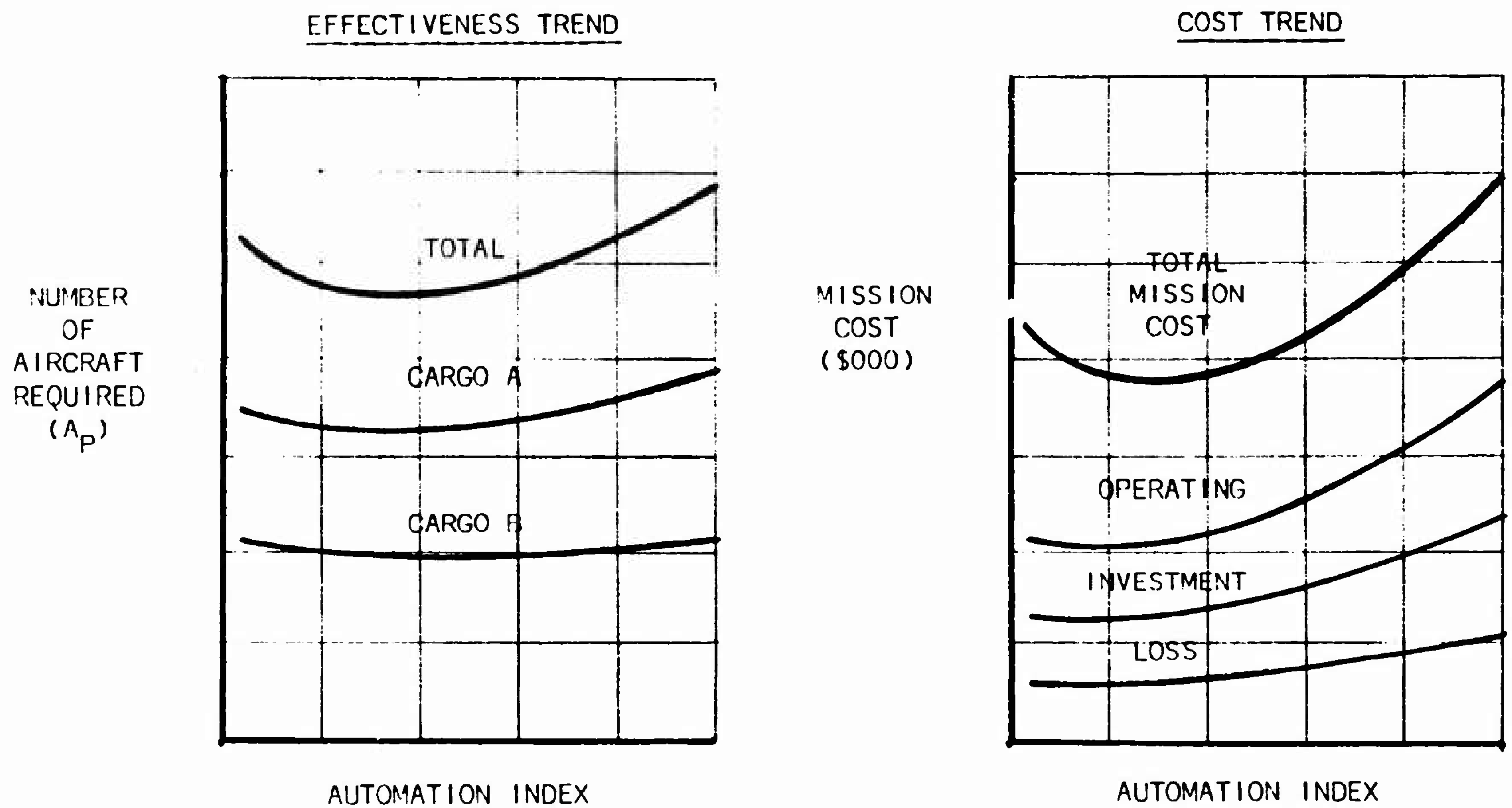


Figure 20. Format for Graphical Analysis of Cost and Effectiveness Trends as the Degree of Cargo Handling System Automation Increases

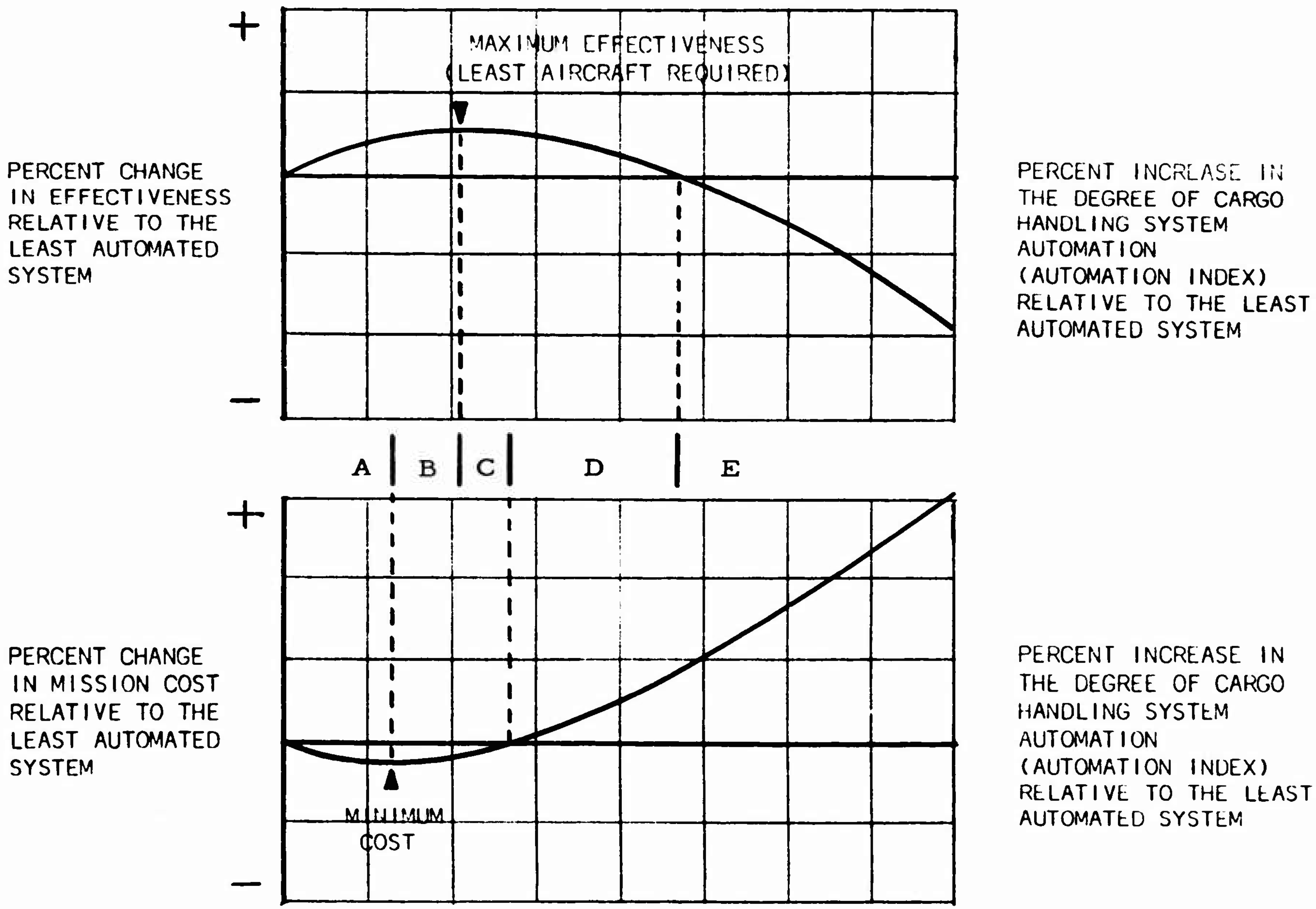


Figure 21. Format for Graphical Analysis of Percentage Gains and Penalties in Cost and Effectiveness as the Degree of Cargo Handling System Automation Increases

At the right of region B, effectiveness is at its maximum. In region B, qualitative considerations, especially regarding airdrop, are quite important. Cost continues to increase while effectiveness begins to decrease in region C. Cost is higher than the cost with the least automated system in region D; effectiveness is decreasing toward the effectiveness of the least automated system. No cargo handling system would be justified in region D unless there were strong qualitative factors to override the cost penalties. In region E, both cost and effectiveness deteriorate rapidly and significantly.

MISSIONS AND AIRCRAFT PARAMETERS

In Phase II of the study, several cargo handling systems were evaluated by using the analytical techniques developed in Phase I. This section of the report presents the development of detail data in several specific areas. These included missions, combat environment, aircraft factors, cargo handling system descriptions, automation index, cargo composition, cargo characteristics, cargo handling times, and costs associated with the performance of the mission. A discussion of each of these areas follows.

EVALUATION MISSIONS

The objective in selecting the missions for the evaluation phase of this study is to choose realistic average missions as a framework within which to evaluate automated cargo handling systems.

Typical Army combat support missions requiring an air line of communications (ALOC) were selected to establish the cargo types and quantities to be used in the evaluation.

The costs and effectiveness resulting from automating cargo handling equipment are analyzed for four aircraft: CV-2B (Caribou), CV-7A (Buffalo), CH-47A (Chinook), and a hypothetical 10-ton STOL aircraft. The three fixed-wing aircraft are evaluated for both the airland and airdrop delivery modes; the single rotary-wing aircraft is evaluated only for airland.

The three missions selected for the evaluation phase were:

1. Mission A – Deployment of the Airmobile Division, including the portion of the 3-day level of supplies and men assigned to the air-transportable vehicles.

2. Mission A – Daily resupply of the Air Assault Division.

3. Mission B – Daily resupply of the forward elements of a ROAD infantry division.

Two delivery modes were employed: airland and airdrop. The same radii were used for all three missions, so that the effect of the composition of the total cargo quantity could be observed. The scope of this preliminary study did not permit varying both radius and cargo composition. Varying both at once would mask the influences of both radius and cargo composition. The quantity of cargo delivered and the total time available in which to complete the delivery remain fixed for any one aircraft and mission.

The missions, aircraft and total cargo quantities, are summarized in Table III. Table IV gives a detailed breakdown of the total cargo quantity

TABLE III

BASIC MISSION AND AIRCRAFT PARAMETERS

	Delivery Mode	Aircraft Type	Aircraft Model	Radius (N. M.)	Total Cargo Quantity (Tons)	Number Operating (Days)
A (Deployment Airmobile)	Airland	Fixed Wing	CV-2 CV-7 10-ton STOL	100	1922 4268 6739	1
		Rotary Wing	CH-47	20	4268	1
A (Resupply Air Assault)	Airland	Fixed Wing	CV-2 CV-7 10-ton STOL	100	741	1
		Rotary Wing	CH-47	20	153	1
	Airdrop	Fixed Wing	CV-2 CV-7 10-ton STOL	150	17	1
B (Resupply ROAD Infantry)	Airland	Fixed Wing	CV-2 CV-7 10-ton STOL	100	107	1
		Rotary Wing	CH-47	20	33	1
	Airdrop	Fixed Wing	CV-2 CV-7 10-ton STOL	150	4	1

TABLE IV

COMPOSITION OF TOTAL CARGO QUANTITY BY TYPE CARGO AND TYPE LOAD

Y	Type Cargo	N	Type Load	Mission A Deployment Airmobile Airland CV-2	CV-7	10 Ton	CH-47	Mission A Resupply Air Assault Airland F.W.	R.W.	Air-Drop F.W.	Mission B Resupply Road Inf Airland F.W.	R.W.	Air-Drop F.W.
1	Pallets	1	Approx 1500 lb	-	-	-	-	55	21	-	-	-	-
		2	Approx 3500 lb	-	-	-	-	213	90	-	75	27	-
		3	Airdrop	-	-	-	-	-	-	17	-	-	4
2	Bulk	4	Large items	-	-	-	-	26	3	-	-	-	-
		5	Small items	-	-	-	-	62	7	-	-	-	-
3	Men	6	240 lb each	334	709	1217	709	5.4	3				
4	POL	7	500-Gal Drums	-	-	-	-	382.	32	-	-	-	-
5	Mixed	8	Pal., Bulk, & POL	-	-	-	-	-	-	-	32.5	-	-
		9	Pallets & Bulk	-	-	-	-	-	-	-	-	6.5	-
6	Vehicles	10-22	Vehicles and Supplies	1589	3559	5522	3559	-	-	-	-	-	-
			TOTAL TONS	1923	4268	6739	4268	743	156	17	107.5	33.5	4

NOTE: "F. W." and "R. W." represent the three fixed-wing aircraft and single rotary-wing aircraft, respectively.

for each mission by aircraft, delivery mode, type load, and type cargo. These cargo quantities are derived from the classes of cargo and the composition of each class as given in the annex of the subject contract (Figures 21 through 24 and Table V). When one-tenth of a vehicle or of a 500-gallon collapsible fuel drum appeared, it was neglected.

A standard 12-hour operating day was assumed for the analysis (Ref. 10, pg. 34).

AIRCRAFT PARAMETERS

The major aircraft parameters required in the framework for evaluating the automation of cargo handling are: flight times, fuel consumption, payload/radius, availability, refueling rate, fuel capacity, cargo compartment dimensions, and restraint factors. Table VI lists these parameters as required for the evaluation.

Mission flight times were determined from the operator's manuals (Ref. 6 and 7) for the CV-2 and CH-47, model specification for CV-7 (Ref. 19), and were assumed for the hypothetical 10-ton STOL based on engineering judgment.

All missions were flown with a cruise altitude of 5000 feet, as at this altitude the aircraft was relatively invulnerable to light ground fire. Retrograde cargo on the return flights was 50 percent of the outbound payload, maintaining the total quantity of retrograde cargo constant for the evaluation of all cargo handling systems.

The availability factor is defined as the percent of the aircraft (including cargo handling system) assigned to the mission that are capable of performing the mission. The tabular data were based on Planning Research Corporation data (Ref. 13, pg. 24 and Ref. 11, pg. 83). Availability of the hypothetical 10-ton STOL was assumed. All aircraft availabilities are derated 10 percent when the more complex conveyor belt system is installed in the aircraft.

An aircraft might be refueled to any percent of capacity, dependent on mission and environment considerations. In this analysis, only the time required to add sufficient fuel for one round-trip mission is charged against that mission. All aircraft are fueled at one-half the maximum fueling rate, with the 10-ton STOL having two assumed rates, depending on the quantity of fuel. The aircraft fuel capacities, the maximum fuel consumption per mission, the refueling rates, and the refueling time per mission which were used in the analysis are listed in Table VI.

AIRCRAFT LOSSES

Aircraft losses due to accidents and enemy fire significantly affect the total mission cost and are included in the analysis. Flights from the logistic

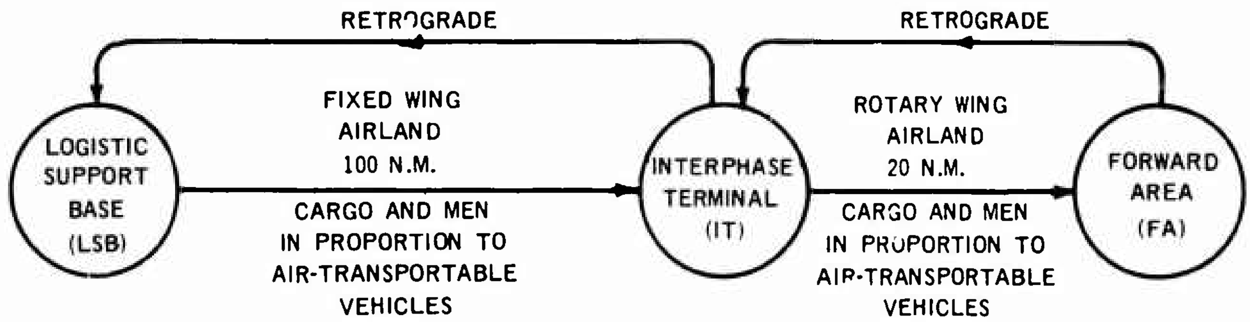


Figure 22. Mission A - Deployment of Airmobile Division

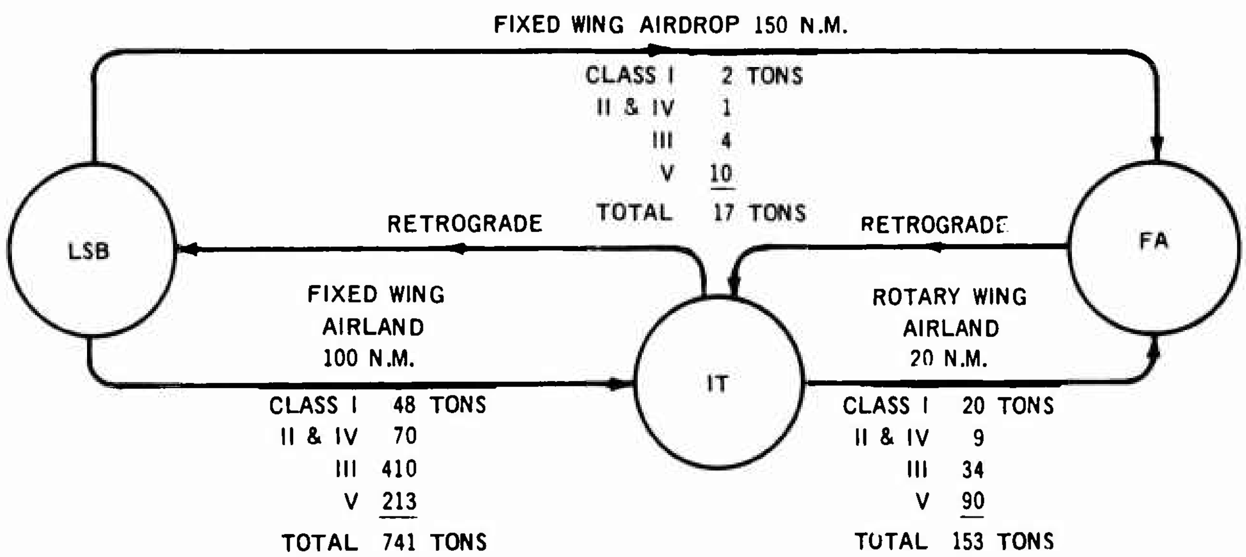


Figure 23. Mission A - Daily Resupply of Air Assault Division

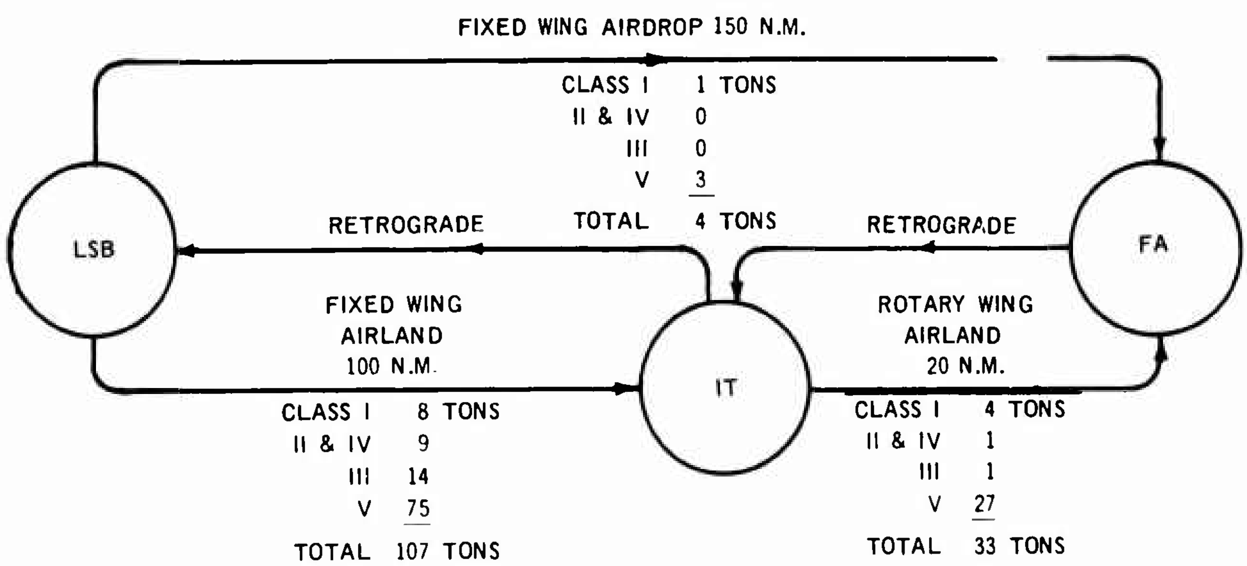


Figure 24. Mission B - 20-Percent Daily Resupply of ROAD Infantry Division

TABLE V

PERCENTAGE COMPOSITION OF CLASSES OF CARGO FROM CONTRACT ANNEX

Class	Pallets: Approx 1500 Lb (%)	Pallets: Approx 3500 Lb (%)	Vehicles (%)	POL: 500 Gal Airland (%)	POL: 5 Gal Airdrop (%)	POL: Bulk (%)
I	100	0	0	0	0	0
II & IV	10	0	5	0	0	85
III	0	0	0	93	93	7
V	0	100	0	0	0	0

TABLE VI

AIRCRAFT PARAMETERS

	Units	CV-2	CV-7	10-Ton STOL	CH-47
Max T.O.G.W	lb	28,500	38,000	62,500	33,000
Operating Wt Empty	lb	19,446	22,400	30,200	17,690
Max Payload (50% return)					
Airland*	lb	7,287	10,600	20,000	14,000
Airdrop**	lb	7,132	10,600	20,000	None
Cargo Compartment					
Length:					
Excl Ramp	in	345	377	345	366
Incl Ramp	in	393	450	445	456
Cargo Compartment Width	in	73	93	147	90
Cargo Compartment Height	in	75	78	98	78
Airland Mode:					
Radius	N.M.	100	100	100	20
Outbound Speed	kn	153	225	400	115
Outbound Flt Time	hr	0.833	0.547	0.352	0.317
Return Speed	kn	154	225	400	130
Return Flt Time	hr	0.832	0.537	0.327	0.229
Airdrop Mode:					
Radius	N.M.	150	150	150	None
Outbound Speed	kn	153	225	400	-
Outbound Flt Time	hr	1.193	0.804	0.510	-
Return Speed	kn	154	225	400	-
Return Flt Time	hr	0.974	0.667	0.375	-
Restraint Factors:					
Fore	g	8.0	8.0	8.0	4.0
Aft	g	2.0	2.0	2.0	2.0
Vertical	g	2.0	2.0	2.0	2.0
Lateral	g	1.5	1.5	1.5	1.5
Availability (%)					
Systems 1-5	%	77	77	72	67
System 6	%	69.3	69.3	64.8	60.3
"P" (1/availability)					
Systems 1-5	1/%	1.30	1.30	1.39	1.49
System 6	1/%	1.42	1.42	1.54	1.66
Max Fueling Rate	gal/min	100	180	350/460	200
Aircraft Fuel Capacity (Usable)	lb	4,836	13,556	21,000	4,029
Fuel Consumption:					
Airland Mission	lb	1,767	2,844	5,550	1,302
Airdrop Mission	lb	1,922	3,730	8,400	None
Allocated Refueling Time					
Airland Mission	min	5.89	4.85	4.83	1.84
Airdrop Mission	min	6.41	6.37	5.61	None

*Airland Radii: 100 N.M. for fixed wing; 20 N.M. for CH-47.
**Airdrop Radius: 150 N.M.

support base to the interphase terminal are not subject to enemy fire. The helicopter is the only aircraft landing in the forward area and is the only aircraft vulnerable to enemy fire while static on the ground. The three fixed-wing aircraft are vulnerable to enemy fire only on airdrop missions, the only time that they fly within 20 nautical miles of the forward edge of the battle area (FEBA).

Ideally, three inputs are required for the analysis:

1. Accident losses per flight hour.

2. Airborne losses to enemy fire per cycle.

3. Probability of loss to enemy fire while on the ground as a function of static exposure time.

These factors depend on the aircraft and the specific tactical situation assumed.

Accidental losses per flight hour are classified; average accidents per cycle are not. Data of both types arrived during the study period. To remain consistent with other vulnerability data available, the latter were used in the study. As the flight time for any aircraft/delivery mode combination is the same for all cargo handling systems, accidents per flight hour would add little to the study results.

Planning Research Corporation cites the following combat accident loss factors per 100,000 sorties (Ref. 11, pg. 83).

CV-2B	CV-7A	C-130B	CH-47A
20	20	17	40

These were used in the evaluation. The C-130B accident loss factor was used for the hypothetical 10-ton STOL, as the latter would probably also be a four-engine aircraft.

While an excellent (classified) study (Ref. 21 through 23), including a sophisticated model of airborne vulnerability to ground fire and a significant amount of data, did arrive during the study period, none of the requested data from the six sources of information on aircraft vulnerability while on the ground became available. As only the CH-47 spends time on the ground in the forward area in this study, the shortage of data did not seriously affect the study results.

The PACE ground-to-air study contained data (unclassified) on aircraft lost to enemy fire per cycle, including both airborne and static ground losses. This same section of the study contained unclassified data on the percent of

downed aircraft that are a total loss (48 percent) (Ref. 22, pg. R-8). In the words of the author,

> The reported Vietnam probabilities for fixed and rotary wing Army aircraft are:
>
> | | |
> |---|---|
> | Odds of being hit on any sorties | 1:370 |
> | Odds of being hit and downed | 1:8400 |
> | Odds of being hit and lost | 1:17,500 |
>
> The data are representative of one type of situation, namely Vietnam; the specific threats encountered on particular flights are not defined. It is not possible to extrapolate attrition or damage under different environmental and threat situations.

Because these data were for a typical Army operation, and were the only available data including aircraft lost while on the ground, they were used in the analysis. The vulnerability analysis accounts for all factors except the decrease in CH-47 losses to enemy fire while on the ground as the exposure time per exposure decreases. Losses of this type are included in the loss/cycle to enemy fire factor, but no reasonable approach was found to include the effect of the duration of each exposure on the aircraft lost. If data were available, exposure time could readily be incorporated in the analysis.

CARGO HANDLING SYSTEMS

This section describes the cargo handling systems evaluated in this study. To assure that the range of automation (from manual to highly automated) was covered, 13 systems were defined in general terms. Table VII shows a matrix of the systems and how each type of cargo is accommodated with each system.

From the list of 13 systems, six were chosen for evaluation and are illustrated in Figure 25. The criteria for selection were: the six systems should be as evenly spaced as possible over the automation index range; the systems should be the best systems available within the specific range for automation; and operational systems should be used where possible. The systems marked with an asterisk in Table VII were chosen for the evaluation.

The automation index was calculated for each of the six cargo handling systems for each type of cargo handled by using the functional evaluation method developed in Phase I of the study. All functions involved in the loading, restraint, and unloading processes were assumed to be performed either consecutively or concurrently. The manner in which each function was performed with a particular system was determined, and all functions were assigned a rating from manual (0) to highly automated (6). The resulting automation index for each cargo handling system is shown in Table VIII by the type of cargo handled.

DESCRIPTION OF SYSTEM 1

This system has a minimum of automation and establishes a base line for the analysis. In this system the cargo is moved, guided, positioned, and restrained manually. A rolling pry bar is provided to aid in the handling of heavy, bulky cargo. The cargo is restrained by MC-1 (5000-pound capacity) tiedown straps, utilizing cargo rings which are in the aircraft and are not considered as part of the system.

Cargo which has been palletized on standard 40-inch-by-48-inch wooden pallets would be pushed and/or pulled into the cargo compartment using manpower aided by the rolling pry bar. The loadmaster predetermines the location of cargo for proper weight and balance of the aircraft, and the cargo is moved to this location and secured with the proper number of MC-1 tiedown straps to meet the load factors of the aircraft. The complete operation is performed with manpower.

Bulk cargo is handled in much the same manner. Small cargo may be hand carried into the aircraft. Large bulk cargo is pushed and/or pulled, aided by the rolling pry bar. Locating and restraining are carried out as described above.

TABLE VII

MATRIX OF CARGO HANDLING SY

SYSTEM CODE	AUTOMATION INDEX (PALLETS)	PALLETS		VEHICLES	
		MOVEMENT	RESTRAINT	MOVEMENT	RE
1	0	Break bulk and hand hand carry	Rope	Drive on	Rope
2*	18	Wheeled pry bar	Cargo straps (MC-1)	Drive on	Strap
3*	36	Rub strips and winch	Straps	Drive on	Strap
4*	42	Skate wheel conveyors and buffer boards w/winch	Cargo straps (MC-1)	Drive on	Strap
5	52	Rollers and detent latching system w/ rigid pallets loads prepalletized	Detent latching	Drive on	Strap
6	52	Rollers and detent latching system w/ rigid pallets loads prepalletized	Detent latching	Prepalletized vehicles on rigid pallets with rollers	Palle
7	52	Semiflush rollers nonpowered	Latching system in guide rail, manual actuation	Drive on	Nom devi
8	64	Rub strips and winch	Latching system in guide rail, manual actuation	Drive on	Exte from
9*	68	Semiflush rollers nonpowered w/winch	Latching system in guide rail, manual actuation	Drive on	Stra
10	95	Power rollers for rigid pallets	Detent latching	Prepalletized vehicles on rigid pallets with rollers	Pall
11	105	Power rollers for rigid pallets	Automatic detent latching	Prepalletized vehicles on rigid pallets with rollers	Auto dete
12*	108	Carwash chain w/unpowered semiflush rollers	Integral with carwash chain	Carwash chain	Integ clan on c
13*	120	Full-width powered conveyor	Barrier net and automatically adjusted overhead net	Full-width powered conveyor	Barr auto adju net

*Indicates systems selected for evaluation.

TABLE VII

CARGO HANDLING SYSTEMS CONSIDERED

VEHICLES		POL		BULK	
MOVEMENT	RESTRAINT	MOVEMENT	RESTRAINT	MOVEMENT	RESTRAINT
Drive on	Rope	Manpower	Rope	Manpower	Rope
Drive on	Straps	Wheeled pry bar where possible otherwise as above	Straps	Same as POL	Straps
Drive on	Straps	Winch	Straps	Winch or manpower	Straps
Drive on	Straps	Same as pallets or manpower	Straps	Same as POL	Straps
Drive on	Straps	Same as #1	Straps	Same as #1	Straps
Prepalletized vehicles on rigid pallets with rollers	Pallet latching	All POL pre-palletized and handled as pallets	Pallet latches	Same as POL where possible and #1 in other cases	Latches and straps
Drive on	Nomex webbing device	Expendable pallets using latching system	Straps	Expendable pallets	Straps
Drive on	Extendable hook from vehicle	Winch	Straps	Winch or manpower	Straps
Drive on	Straps	Winch	Straps	Winch or manpower	Straps
Prepalletized vehicles on rigid pallets with rollers	Pallet latching	All POL pre-palletized and handled as pallets	Pallet latches	Same as POL where possible and #1 in other cases	Latches and straps
Prepalletized vehicles on rigid pallets with rollers	Automatic detent latching	All POL pre-palletized and handled as pallets	Automatic detent latching	Same as POL where possible and #1 in other cases	Automatic detent latching and straps
Carwash chain	Integral vehicle clamping device on carwash chain	Carwash chain	Straps	Carwash chain and rollers	Straps
Full-width powered conveyor	Barrier net and automatically adjusted overhead net	Full-width powered conveyor	Barrier net and automatically adjusted overhead net	Full-width powered conveyor	Barrier net and automatically adjusted overhead net

B

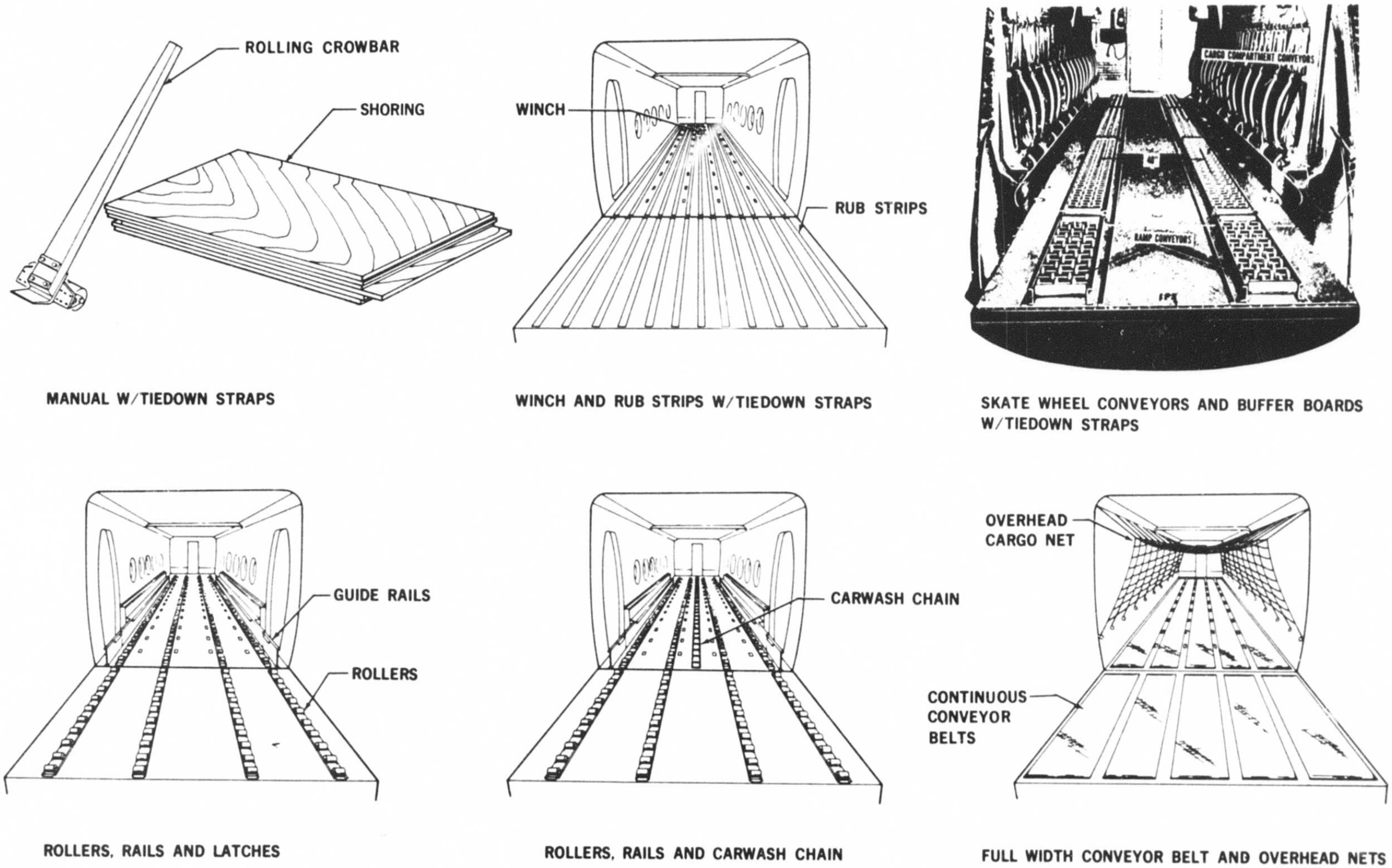


Figure 25. Six Systems Selected for Evaluation

TABLE VIII

AUTOMATION INDEX

Cargo Types	Cargo Handling System					
	1	2	3	4	5	6
Pallets	18	36	42	68	108	120
Bulk	18	36	36	36	36	120
Men	12	12	12	12	12	12
POL	18	40	40	40	40	120
Mixed - Fixed Wing	18	37	39	47	58	120
- Rotary Wing	18	36	36	40	58	120
Vehicles	12	18	18	18	40	120
Airdrop Pallets	-	-	60	91	102	-

POL in 500-gallon fabric containers is rolled into the aircraft by manpower (palletized in CV-2B aircraft). It is secured with MC-1 tiedown straps utilizing the rings at each end of the container.

Vehicles are driven into the aircraft and guided by the use of hand signals. They are located in the proper predetermined position and restrained with tiedown straps.

This system does not lend itself to airdrop operations utilizing extraction parachutes. Cargo could be pushed out or dropped out manually, but this is a dangerous operation and is not advisable. It is assumed that airdrop cannot be performed with this system.

Because of the simplicity of the system, there is no conversion time required to convert the aircraft from cargo to vehicle missions. This system does not lose efficiency when handling mixed retrograde loads. Loading time is dependent only on the speed and quantity of the troops involved in the loading and unloading of the aircraft for any type of cargo. There is no equipment, except the rolling pry bar, which could fail and prevent operation of the system. Failure of the pry bar would not make the system inoperative, but would only increase time in the loading and unloading process.

DESCRIPTION OF SYSTEM 2

This system adds two aids to the first degree of automation; namely, a prime mover and a friction reducing device. An electrically operated winch provides the means for moving the cargo either from the ground or from truck-bed height to the proper location within the cargo compartment. Nylatron rub strips bonded to the cargo floor reduce the force necessary to move the cargo.

Guidance of the cargo, while assisted somewhat by the winch cable, must still be mostly provided by manpower.

Location of the cargo is still a manual operation, as is the restraint of the cargo.

This system handles the four types of cargo in the same manner as described under system 1. It is not practical for airdrop operations, but will handle mixed and retrograde loads with little or no conversion time.

The failure of the winch would not affect the completion of the mission except for the time to load or off-load and the need of manpower to move the cargo. A winch failure would place this system in the same category as system 1.

DESCRIPTION OF SYSTEM 3

This system is presently installed in the CV-2 and consists of skate wheel conveyors for reducing friction, buffer boards for guidance, and a winch for reducing manpower. This system is shown in Figure 26.

The skate wheel conveyors are 12 inches wide and consist of 12 rollers per foot of length. There are three wheels per axle which are mounted between aluminum channels. These conveyors are made in 10-foot lengths, or as required to fit the cargo deck. Securing of the conveyors to the floor is accomplished by quick-operating fasteners, utilizing the cargo rings in the floor.

The buffer boards, or guide rails, are plywood which is 8 inches wide by 1/2 inch thick and are covered on both sides with 0.040-inch-thick aluminum sheet. Fittings are provided to secure them to the aircraft structure for rigidity. Provisions must be made in the aircraft structure to facilitate installation.

Cargo can be palletized on 463L type pallets; the 40-inch-by-48-inch wooden pallets can have solid bottoms or can be placed on a plywood base. These pallets may be pushed by hand or pulled into the aircraft by the winch. Stowage location decision to assure weight and balance of the aircraft will be manual, as will the securing of the cargo. The securing operation is

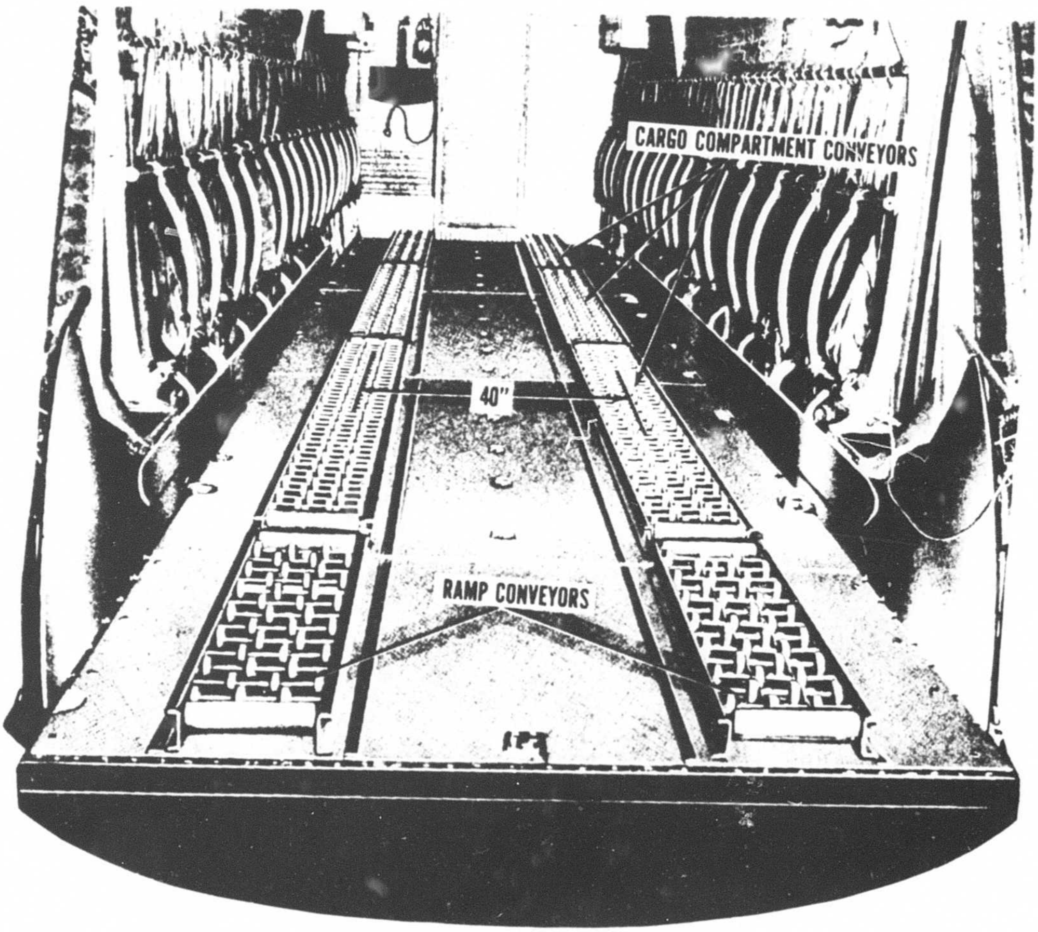


Figure 26. Cargo Handling System 3

performed by using the required number of MC-1 tiedown devices and/or cargo nets attached to the tiedown rings.

Bulk cargo can be handled in the same manner as described for system 1 with conveyor sections removed and stored. The conveyor sections could be temporarily placed on the floor to allow easier loading of small cargo which could be rolled along the conveyor.

Vehicles will be loaded, located,and secured in the same manner as described for previous systems. Any conveyor sections positioned in the vehicle wheel tread area must be removed and stored.

It will probably be necessary to remove all conveyor sections for the loading of POL in 500-gallon fabric containers to avoid puncturing and/or tearing the fabric.

This system is the first to allow airdrop of palletized cargo. The procedure for extraction is described in various handbooks and will not be discussed in this report, except to say that just before extraction the palletized cargo is unrestrained in all directions and creates a potentially dangerous condition.

When a change is being made from one type of cargo to another, it will be necessary to remove portions of this system from the floor of the aircraft. In all changes, the buffer boards can remain in place. When vehicles are being driven aboard, caution must be exercised to prevent damage to the buffer boards. The conversion from one mission to another can be accomplished in a relatively short period because only the conveyors are affected.

A complete failure of this system is improbable. A skate wheel roller coul be damaged but would not prevent the cargo from being loaded and unloade A section of buffer board could be damaged which would prevent airdrop of cargo because of the lack of guidance in that area, but loading would not be greatly affected. Reasonable caution would be exercised during loading and off-loading to prevent further damage to the buffer boards or aircraft structure.

DESCRIPTION OF SYSTEM 4

This system contains the features of the 463L system as used in several existing aircraft. The system is the same as the system installed in the CV-7A prototype aircraft. Slight modifications of the CV-7 system will permit it to be installed in any of the four aircraft being evaluated.

The system (see Figure 27) consists of guide rails with complex integral latches which engage notches in the edge of aircraft pallets. Mating lips on the pallet and guide rail provide vertical restraint and lateral guidance. The locks are operated by manual controls located on a panel at the forwar end of the aircraft. Roller conveyors fastened to the floor by quick disconnect fasteners provide a surface for moving palletized cargo into the aircraft.

This system has been designed to be used specifically with 463L pallets and Army Comex platforms. The system will handle palletized cargo easi as long as the cargo is placed on the proper pallet.

When bulk cargo is being carried, it will sometimes be necessary to remo the roller conveyors. Bulk cargo will then be handled similarly to system Bulk cargo must be restrained with MC-1 tiedown straps secured to the de cargo tiedown rings.

Transportation of POL in 500-gallon fabric drums will usually require removal of the roller conveyor sections to guard against puncturing the

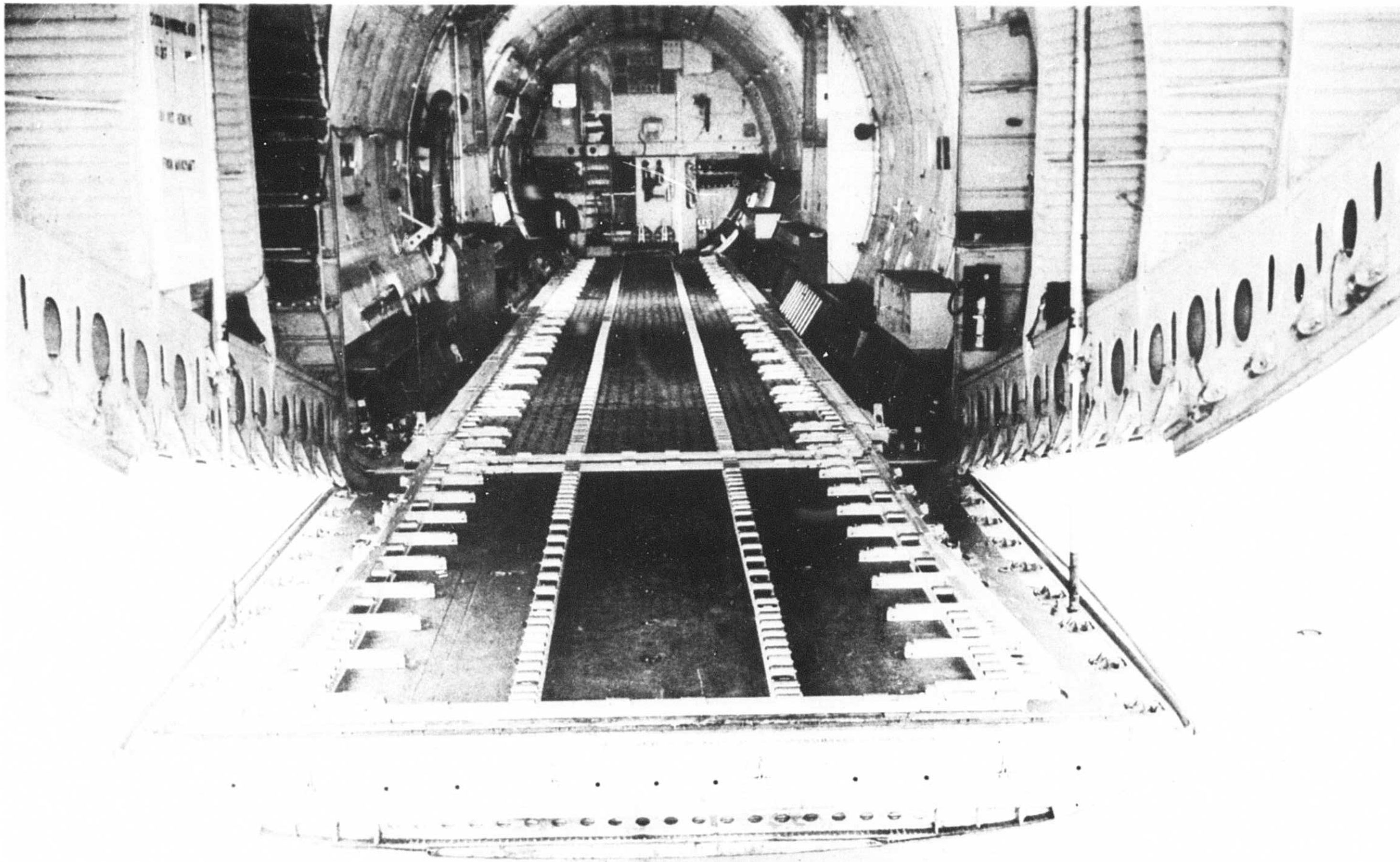


Figure 27. Cargo Handling System 4

fabric. When removed, the conveyors are stored under removable floor panels of the aircraft. For vehicle missions, the conveyors in the treadway area must be removed and stowed.

This system surpasses system 3 for aerial delivery of cargo. This was one of its primary design requirements. The cargo pallet is restrained in all directions until the action of the extraction chute overcomes the preset spring load in the restraint locks. The danger of unrestrained cargo is completely eliminated.

In most cases, only the roller conveyors must be removed to convert from one type of cargo to another.

For vehicles, only those conveyors in the treadway area need be removed and stored. Caution must be exercised while loading and unloading vehicles to prevent damage to the guide rails and locks. These locks are both complicated and expensive. Because of the locks, the guide rails are also expensive with this system.

It is difficult to have a failure within the system that would cause a mission failure. One set of locks (namely, the left-hand locks on the CV-7A) can be actuated by one of two separate control systems. A failure to both at the same time is very remote. The other set of locks is preset to resist a known extraction force. Should the locks fail to open under this force, manual actuation of an emergency release handle will release all the locks simultaneously. If these locks failed to open because of a linkage failure in the emergency release system, it would be necessary to abort an airdrop mission.

DESCRIPTION OF SYSTEM 5

This system consists of an endless link chain (similar to a carwash chain), roller conveyors, and guide rails. For movement into the aircraft, the loaded pallets would be secured to the link chain by fittings. The system envisioned (see Figure 28) would also feature an automatic longitudinal restraint through the chain link fittings. Lateral and vertical restraint is provided by the guide rails which are similar to system 4 without the restraint locks. A man is required to operate a power switch to start the cargo in one direction or the other or to stop the motion at the proper location.

This system would work very well with palletized cargo either on a 463L type pallet, a special design with integral fittings compatible with the endless chain, or an inexpensive pallet with the restraint fittings integral with the chain.

Bulk cargo should be palletized on plywood skids or on 40-inch-by-48-inch pallets with flush bottoms. Otherwise, the roller conveyors must be re-

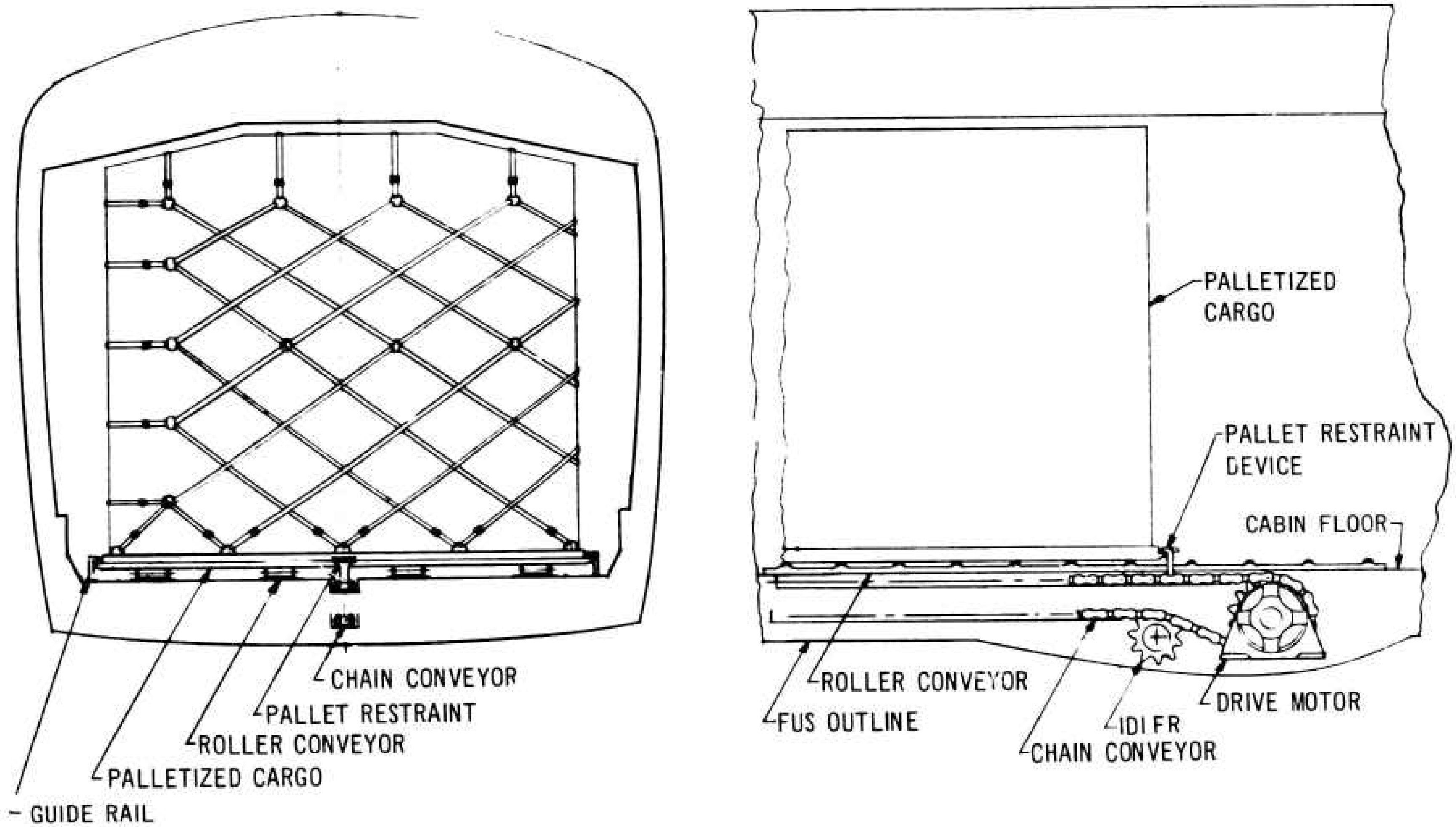


Figure 28. Cargo Handling System 5

moved to provide a level floor area. The chain would be buried in a recessed trough in the floor, eliminating the need to remove and stow the chain for vehicle or bulk cargo missions. Bulk cargo, hand carried or rolled into the aircraft, will be secured by using a cargo net or MC-1 tiedown straps.

POL in 500-gallon fabric containers will require removal and storage of the conveyor sections.

Vehicles may be pulled into the aircraft by utilizing the link chain or may be driven into place as in the other systems. In the time analysis for vehicles, it is assumed that a restraint device is used which locks into the chain, thus significantly reducing restraint time. A minimum number of MC-1 tiedown straps will be necessary for complete vehicle restraint.

This system will handle airdrop of cargo by designing the chain attach fittings to release under a given extraction force after actuating a device removing most of the aft restraint. If these fittings are released manually, a period of danger exists before the chute extracts the cargo load.

The time consumed when converting from cargo of one type to that of another is a minimum, since only the roller conveyors must be removed and stored. Semiflush roller conveyors could be utilized which would not require converting in all cases. (Semiflush rollers protrude only 1/2 inch above the cargo floor and are invertible to form a completely flush floor.)

The link chain is the primary element in the system affecting reliability. In the event of a physical failure of the chain during flight under certain flight conditions, the mission could be catastrophic. Failure during loading or unloading would only reduce the automation effect because the cargo could still be loaded and unloaded by hand and secured by the use of MC-1 tiedown straps.

DESCRIPTION OF SYSTEM 6

This system comes the nearest to being a fully automated system, and is still feasible for operation. The system consists of a number of endless belt conveyors which operate over Nylatron skid strips bonded to the cargo deck and overhead nets for cargo restraint. Actuation of the belts is by power actuated drums. The belts are so placed that the cargo tiedown rings are accessible for securing the cargo in case the automated nets may not be desirable. The cargo nets are suspended from the top of the cargo compartment by bungee cords; the lower ends of the nets are attached to torque tubes which, when actuated, pull the nets over the cargo. These torque tubes act in the same manner as those found on lumber trucks for securing lumber. Once the system has been actuated, the complete operation is automatic and is accomplished sequentially by microswitches which automatically terminate one operation and initiate another until the cargo is completely secured. A sketch of this system is shown in Figure 29.

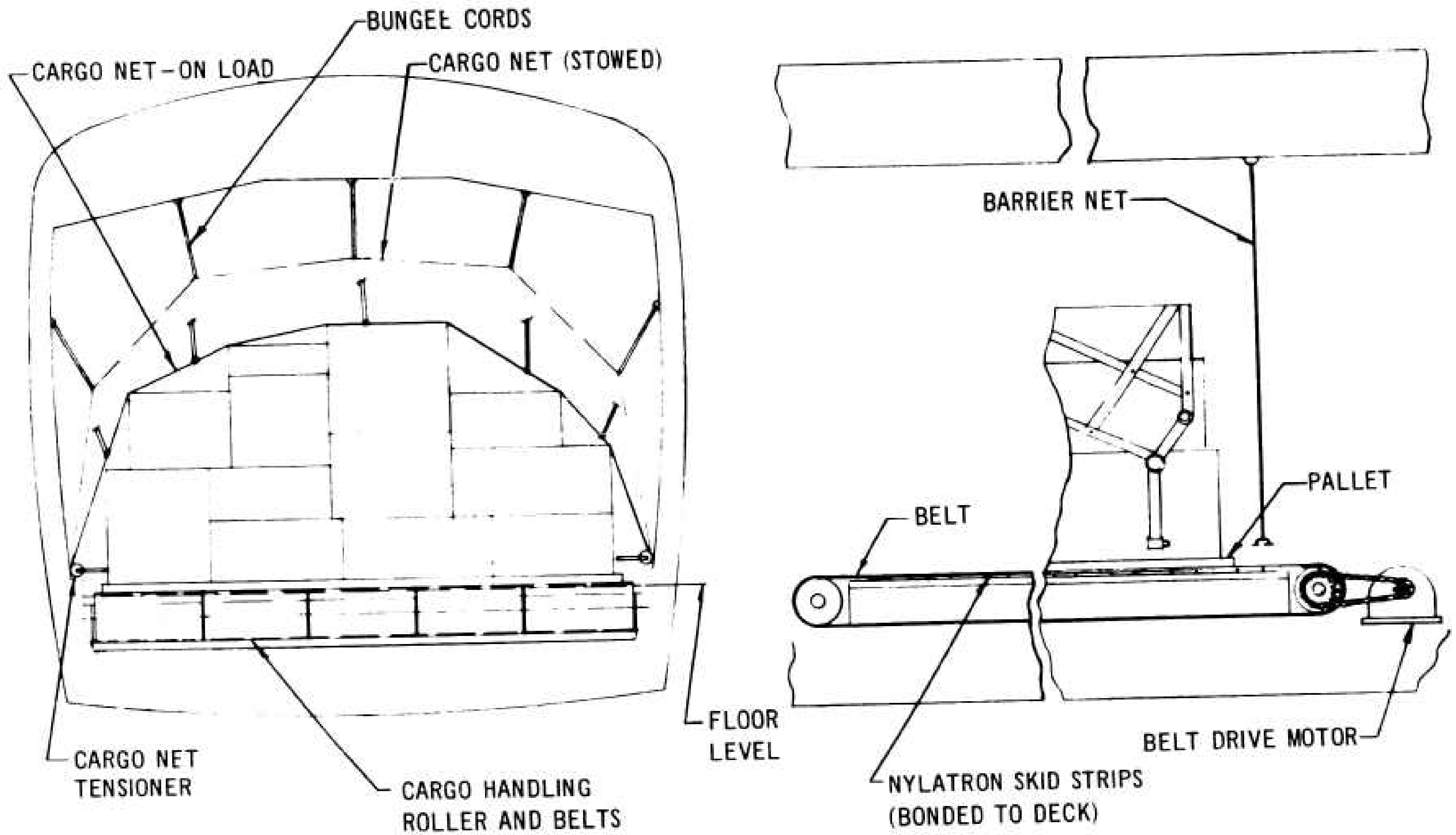


Figure 29. Cargo Handling System 6

All types of cargo can be placed in the cargo compartment and secured by this system. Vehicles can be conveyed by the belts or driven in under their own power.

This system does not readily lend itself to airdrop operations. The airdrop capabilities could be designed into the system, but cost and weight penalties make this unrealistic.

The failure of any one component of this system would not necessarily cause a mission failure, but loading or the removal of cargo from the aircraft would be very time-consuming.

WEIGHT AND COST CALCULATIONS

Table IX shows the weight and cost computed for each cargo handling system for each aircraft, and Tables X through XV show the weight and cost of the individual components which make up each system. The weights and costs of systems are not appreciably different between aircraft because the length of the cargo floor is nearly the same in all cases (CV-2 excepted). In system 5, the weight and cost of the system are influenced by the aircraft payload because the chain must be designed to withstand the restraint requirements of a full payload. Weight and cost of system 6 are influenced by the aircraft width because the endless belting is required to cover the entire floor. The effects of the cargo handling system weights on the available aircraft payload (payload degradation) are also shown in Table IX.

Weight and cost figures are based on knowledge of existing cargo handling systems, commercially available hardware, and engineering estimates. It was beyond the scope of this study to perform a detail design of each system evaluated. Each system was defined and supported with adequate preliminary design analysis to identify and size the larger components. In the case of both cost and weight, the data generated are for the cargo handling system only and do not include modifications to the aircraft. It is assumed that provisions for the system were designed into the aircraft. An analysis of modifications required for each aircraft requires a detail load and stress report and is beyond the scope of this study.

AUTOMATED WEIGHT AND BALANCE

The four aircraft studied in this analysis may each be equipped with an automatic weight and balance computing system. Cost and weight of the system will be approximately the same for each aircraft type. As the system, when installed, is not an integral part of the cargo handling equipment, it is not considered in determining the overall costs and weights of the various cargo handling systems.

The weight of the system is made up of a computer and transducers. In aircraft with relatively simple landing gear, the number of transducers required

TABLE IX

CARGO HANDLING SYSTEMS

Cargo Handling System	CV-2B Weight (lb)	CV-2B Cost ($)	CV-2B % Max Payload Available	CV-7A Weight (lb)	CV-7A Cost ($)	CV-7A % Max Payload Available
1	227	79	96.9	415	121	96.0
2	128	3,835	98.2	151	3,983	98.6
3	499	3,855	93.2	786	4,126	92.6
4	437	11,145	94.0	520	12,500	95.0
5	886	8,233	87.8	1,356	9,512	87.7
6	1,858	20,670	74.5	2,375	23,353	77.6

Cargo Handling System	CH-47 Weight (lb)	CH-47 Cost ($)	CH-47 % Max Payload Available	10-Ton STOL Weight (lb)	10-Ton STOL Cost ($)	10-Ton STOL % Max Payload Available
1	426	124	97.0	520	169	97.4
2	151	3,983	98.9	191	4,255	99.0
3	809	4,143	94.2	976	4,305	95.1
4	534	12,780	96.2	514	12,389	97.4
5	1,343	9,564	90.4	1,818	10,214	90.9
6	2,409	23,445	82.8	3,629	27,564	81.9

is small (two per gear or six per aircraft or one per gear of the Chinook or four per aircraft). Transducers weigh about 1 pound each, and the computer weighs about 25 pounds. System weight will be influenced slightly by the size of the aircraft because of the additional wiring; however, this can be ignored without affecting the results. System weight will, therefore, be approximately 30 pounds.

The initial cost of the system is estimated at $7500 at the one-hundredth unit.

TABLE X

WEIGHT AND COST – CARGO HANDLING SYSTEM 1

COMPONENT DESCRIPTION	CV-2		CV-7		CH-47		10-Ton STOL	
	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)
Wheeled Pry Bar	30	35.00	30	35.00	30	35.00	60	70.00
(1) Plywood	(2) 197	44.00	(3) 385	86.00	(3) 396	89.00	(4) 460	99.00
TOTAL	227	79.00	415	121.00	425	124.00	520	169.00

NOTES: (1) Cost \$.33 ft^2 Weight 1.47 lb/ft^2 (2) 4' width (3) 7' width (4) 8' width

TABLE XI

WEIGHT AND COST – CARGO HANDLING SYSTEM 2

COMPONENT DESCRIPTION	CV-2		CV-7		CH-47		10-Ton STOL	
	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)
(1) Winch	75	3500.00	75	3500.00	75	3500.00	75	3500.00
(2 & 3) Nylatron Strips	53	335.00	76	483.00	76	483.00	116	755.00
TOTAL	128	3835.00	151	3983.00	151	3983.00	191	4255.00

NOTES: (1) Western Gear (2) 1.54 lb per ft^2 1/4" thick \$10.00 per ft^2 1/4" thick (3) Assume 1/6 of floor covered

TABLE XII

WEIGHT AND COST – CARGO HANDLING SYSTEM 3

COMPONENT DESCRIPTION	CV-2		CV-7		CH-47		10-Ton STOL	
	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)
Winch	75	3500.00	75	3500.00	75	3500.00	75	3500.00
(4) Skate Wheel Conveyors	(1) 318	300.00	(2) 595	565.00	(2) 515	580.00	(3) 735	750.00
(5) Butter Boards 1/2" plywood	56	12.00	61	13.50	63	14.00	56	12.00
(6) Metal Facing	42	36.00	46	39.50	47	41.00	42	36.00
(7) Fittings	8	7.00	9	8.00	9	8.00	8	7.00
TOTAL	499	3855.00	786	4126.00	[illegible]	4143.00	976	4305.00

NOTES: (1) Two rows (2) Three rows (3) Four rows (4) 5.3 lb/ft \$5.00/ft
(5) 1 lb/ft \$.22/ft (6) .75 lb/ft \$.75/ft (7) 20% of 6

TABLE XIII

WEIGHT AND COST – CARGO HANDLING SYSTEM 4

COMPONENT DESCRIPTION	CV-2		CV-7		CH-47		10-Ton STOL	
	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)
Winch (1)	75	3500.00	75	3500.00	75	3500.00	75	3500.00
Guide rails, latches and controls (2)	280	6990.00	320	8000.00	330	8250.00	316	7900.00
Roller Conveyors (3)	(4) 82	655.00	(5) 125	1000.00	(5) 129	1030.00	(5) 123	989.00
TOTAL	437	11145.00	520	12500.00	534	12780.00	514	12389.00

NOTES: (1) Winch weight and cost are from Western Gear
(2) Guide rails, latches and controls (weight and cost) based on information from Brooks & Perkins, Inc.
(3) Roller Conveyors (weight & cost have been estimated)
(4) Three rows of conveyors
(5) Four rows of conveyors

TABLE XIV

WEIGHT AND COST – CARGO HANDLING SYSTEM 5

COMPONENT DESCRIPTION	CV-2		CV-7		CH-47		10-Ton STOL	
	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)
(1) Carwash chain	(2) 366	(2) 358	(2) 712	(2) 1062	(2) 691	(2) 1024	(2) 1097	(2) 1724
Sprocket (2)	(2) 60	(2) 64	(2) 113	(2) 104	(2) 113	(2) 104	(2) 173	(2) 145
Shaft (2)	(3) 45	(4) 54	(3) 45	(4) 54	(3) 45	(4) 54	(3) 45	(4) 54
Pillow Blocks (4)	(2) 41	(2) 76	(2) 41	(2) 76	(2) 41	(2) 76	(2) 41	(2) 76
Chain Tiedown	(3) 20	(4) 28	(3) 30	(4) 36	(3) 30	(4) 36	(3) 40	(4) 48
Cargo Tiedown	(3) 60	(5) 135	(3) 80	(5) 180	(3) 80	(5) 180	(3) 90	(5) 203
Drive Motor	(6) 75	(7) 5000	(6) 75	(7) 5000	(6) 75	(7) 5000	(6) 75	(7) 5000
Roller Conveyors	(12) 101	(12) 806	(10) 125	(10) 1000	(10) 129	(10) 1030	(10) 123	(10) 989
Guide Rails	(8) 118	(9) 1612	(8) 135	(11) 2000	(8) 139	(9) 2060	(8) 134	(9) 1975
TOTAL	886	8133	1356	9512	1343	9564	1818	10214

NOTES:

(1)

		CV-2	CV-7	CH-47	10-Ton STOL
Length	=	60.3	66.4	64	60.3
Wt/ft	=	6.8#/ft	10.8#/ft	10.8#/ft	18.2#/ft
Total Wt	=	366#	712#	691#	1097#

(2) Information from Boston Gear Co. Cat.

(3) Estimated weight

(4) $1.25/lb

(5) $2.25/lb

(6) Estimate

(7) Estimate

(8) 1.8#/ft

(9) Ratio of length based on $2000 for CV-7

(10) See System 4

(11) Base estimate

(12) Using four rows

TABLE XV

WEIGHT AND COST – CARGO HANDLING SYSTEM 6

COMPONENT DESCRIPTION	CV-2		CV-7		CH-47		10-Ton STOL	
	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)	Weight (lb)	Cost ($)
Nylatron skid strips (4" apart under belt)	(1)127	(3) 810	(12)193	(3) 1235	(17)199	(3) 1272	(20) 335	(3) 2140
Belt (18" wide)	(2&4)653	(5) 1266	(4&13)930	(5) 1800	(4&18)958	(5) 1855	(19&4)1610	(5) 3110
Drive Motor (two required)	(6)200	(6)10000	(6)200	(6)10000	(6)200	(6)10000	(6) 200	(6)10000
Shaft (four required)	(7)250	(8) 300	(7)292	(8) 350	(7)292	(8) 350	(7) 464	(8) 556
Pillow blocks	(9&10)128	(11) 294	(14&10)160	(11) 368	(14&10)160	(11) 368	(21&10) 320	(11) 588
Overhead net restraint system	(15)500	(16) 8000	(15)600	(16) 9600	(15)600	(16) 9600	(15) 700	(16)11200
TOTAL	1858	20670	2375	23353	2409	23445	3629	27564

NOTES:
(1) Fifteen required (481 ft) (.258#/ft)
(2) Three belts (211 ft)
(3) $1.65/lb
(4) 3.1#/ft
(5) $6.00/ft
(6) Basic motor larger due to friction
(7) Full width
(8) $1.20/lb
(9) $4 per shaft
(10) 8 lb each
(11) $18.40 each
(12) Twenty required (750 ft) (.258#/ft)
(13) Four belts (300 ft)
(14) Twenty required
(15) Estimate
(16) $16/lb
(17) Twenty required (772 ft)
(18) Four belts (309 ft)
(19) Seven belts (520 ft)
(20) Thirty-five required (1300 ft)
(21) Thirty-two required

CARGO LOADS

In order to estimate accurately the cargo handling time for cargo handling systems installed in Army aircraft, type-loads were composed. These type-loads were created for each aircraft and for each appropriate cargo type (inappropriate cargo would be airdrop pallets in the CH-47). The loads are illustrated in the appendix. These figures also show the capacities and cargo-carrying capabilities of each aircraft. The dimensions of the 10-ton STOL were based on the C-123, except that the width of the floor was increased to accommodate a 3/4-ton truck and a 1/4-ton truck side by side. Center-of-gravity limitations were met in the CV-2 and CH-47. No center-of-gravity requirements were known for the CV-7 and 10-ton STOL, but the center of gravity of each load was computed so that it fell within a probable range of center-of-gravity values.

Type-loads are necessary to provide a basis for accurate load and off-load time estimates. Type-loads were composed using the basic criteria that loads must assess the full cargo handling system weight penalty unless volume limited, giving due consideration to the cargo transported in Army aircraft. The approach used in forming the cargo loads varies with the cargo type. The cargo classifications for which type-loads were created are pallets, bulk cargo, POL, vehicles, troops, mixed loads, airdrop loads, and retrograde cargo. Each cargo type is treated separately in the subsequent discussion.

PALLETS

Two type-loads containing pallets were formed for each aircraft model. The supply cargo was assumed to be unitized on 40-inch-by-48-inch pallets. The basic weight of each pallet was varied, depending on the density of the cargo carried. Based on mission resupply requirements, for Class I and Class II type cargo, pallets weighed 1500 pounds, and for Class V type cargo, pallets weighed 3500 pounds. The pallet type-loads are shown in the appendix.

The pallets were loaded into each aircraft until their combined weight most nearly equaled the ACL of the aircraft. Since various cargo handling systems of different weights were analyzed, the weights of the pallet loads were assumed to be flexible and sufficient supplies were off-loaded to account for weight differences of the various cargo handling systems. For the heavier systems (5 and 6), where the system weight is near a pallet weight, a complete pallet is off-loaded. This has little effect on the loading and unloading times because 40-inch-by-48-inch pallets are repalletized on larger pallets for system 5, and the time to load a larger pallet is relatively independent of the pallet weight. For system 6, the belt conveyors move at a constant speed regardless of the number of pallets loaded.

BULK CARGO

Two types of bulk cargo loads were defined for each aircraft. These consist of (1) cargo greater than pallet (GTP) size (in any one dimension), and (2) cargo less than pallet (LTP) size.

The selection of cargo that is representative of normal bulk cargo is very difficult. The range in size, shape, and weight of these cargo items is almost limitless.

It is necessary to examine the impact that bulk cargo has on the results of the evaluation of cargo handling systems. Reiterating the objectives of type-loads, we recall that the type-loads must be definitive enough to allow accurate estimation of cargo handling times and flexible enough to allow utilization of the available aircraft payload.

For the evaluation, then, it is not of too much importance to define exactly what items are selected for the type-loads as long as they are representative pieces of military equipment. Using this approach to the problem, the following selection was made for bulk cargo. Items are not identified, but the dimensional and weight data are from actual military supplies and equipment (see Table XVI).

TABLE XVI

BULK CARGO – GREATER THAN PALLET SIZE

Item	Dimensions (in)			Weight (lb)	Cube (ft^3)
	Length	Width	Height		
1	80	49	76	2303	172.5
2	98	45	40	1600	102
3	124	69	64	3000	317
4	60	36	48	1800	60
5	48	24	23	511	15.4
6	50	26	24	770	18
7	52	25	43	1271	32.3

Bulk cargo for loads made up of items less than pallet size was selected to make increments of cargo which weigh 500 pounds each. Several increments (including fractional increments) were then combined to arrive at aircraft payload. The actual items included in a 500-pound increment are shown in Table XVII.

TABLE XVII

BULK CARGO – LESS THAN PALLET SIZE

Quantity	Dimensions (in)			500-Pound Increment			
	Length	Width	Height	Weight (lb)	Cube (ft^3)	Total Weight (lb)	Total Cube (ft^3)
4	12	14	9	32	0.9	128	3.6
1	12	15	15	50	1.56	50	1.6
2	12 Dia.		15	68	0.98	136	2.0
1	36	24	54	88	27.	88	27.0
1	24	24	18	98	6.	98	6.
						500	40.5

Greater-than-pallet-size cargo items were selected which will use all of the available payload of the aircraft as nearly as possible. This established the number of items in the load. The weight of each bulk load was adjusted on a proportional basis to meet the exact aircraft payload capacity. Cargo handling times were then computed for the total load. As cargo handling system weight increases, the weight of items of cargo is proportionally reduced so that the weight of the cargo equals the available aircraft payload. Time estimates were made using only the item weights and the number of items.

Aircraft loads of bulk cargo less than pallet size were made up of a number of 500-pound groups of cargo (as defined in previous section) according to the following formula:

$$\text{Number of Cargo Increments} = \frac{\text{Available Aircraft Payload}}{\text{500 Pounds}}$$

With a particular cargo handling system, the cargo handling time for one 500-pound cargo increment was estimated and the total loading time was obtained by multiplying the single increment time by the number of 500-pound increments.

TROOPS

The CV-2, CV-7, and CH-47 aircraft are equipped to accommodate passengers, and the 10-ton STOL is assumed to be so equipped. The number of troops to be loaded into each aircraft is a function of the space available, the ACL, and the weight of the cargo handling system. As the cargo

handling systems are added to the aircraft, the allowable payload allotted for cargo or troops will be reduced. It can be seen in Table XIX that three of the aircraft are space limited. In the 10-ton STOL and the CV-7, 660 pounds of cargo handling equipment can be added before the effect of system weight will displace troops. The CH-47 will accommodate the heaviest of cargo handling systems without displacing troops. On the other hand, the CV-2 is payload limited without any cargo handling system aboard the aircraft and requires the displacement of additional troops when heavier cargo handling systems are considered. The placing of these troops did not have an appreciable effect on the loading or off-loading times. The time required for loading is largely dependent upon the time it takes the first man to walk to the front of the aircraft. The troops are assumed to board the aircraft in columns of two for the CV-2, CV-7, and CH-47 and in columns of four for the 10-ton STOL. Assuming that the men all walk at the same speed and are spaced approximately one seat apart, the first and last man would reach their seats at the same time. The time to load the troops would not be dependent on the length of the column.

In the deployment mission, the number of troops to be moved is assumed to be in direct proportion to the number of vehicles to be moved. The troops that are assigned to vehicles outsize to a particular aircraft are subtracted when it is found that the vehicle cannot be loaded. The number of troops to be moved and the capacities of the aircraft are shown in Table XVIII.

TABLE XVIII

TROOPS TRANSPORTED

Aircraft	Aircraft Capacity: Space Limited (men)	Aircraft Capacity: Payload Limited (men) *	Payload (lb)	Total Number of Troops to Deploy
10-Ton STOL	80	83	20,000	10,142
CV-7	41	44	10,600	5,912
CH-47	33	58	14,008	5,912
CV-2	32	30	7,290	2,778

*Each man weighs 240 pounds

POL (PETROLEUM, OIL, AND LUBRICANTS)

POL loads were defined based on the breakdown of resupply cargo in the contract annex and are shown below:

1. Ninty-three percent of the POL will be carried in 500-gallon collapsible fabric drums.

2. Remaining POL is to be packaged but loose.

3. POL to be airdropped is carried in 5-gallon cans.

No type-loads were generated for the 7 percent of the POL that was packaged; it was assumed that it would be included in the bulk loads. The POL to be airdropped is discussed on the following pages.

The 500-gallon collapsible drum is 80 inches long by 47 inches wide when filled and weighs approximately 3550 pounds. It is designed to be rolled into the aircraft and tied down with its rolling axis perpendicular to the length of the aircraft.

The width of the CV-2 is too narrow to load the 500-gallon fuel drum with its rolling axis perpendicular to the length of the aircraft. To load the drum in the CV-2, it is necessary to place it on a pallet and to load it with its length parallel to the length of the aircraft. POL loads are not shown for the CV-2 because they were treated as pallet loads and required no new analysis. The type-loads for the CV-7, CH-47, and 10-ton STOL are shown in the appendix.

The amount of fuel carried as cargo was varied with each cargo handling system to account for variations in cargo system weight. All aircraft were then grossed out to the maximum ACL by using a combination of POL weight and cargo system weight.

MIXED LOADS

The mixed loads were composed from the supplies specified in the Mission B resupply requirements. The tonnages of supply required are shown in Table XIX.

TABLE XIX

MIXED LOAD TONNAGES

Item	Fixed Wing (tons)	Rotary Wing (tons)
1500-pound pallets	8.9	4.1
POL	13.0	0.9
Bulk	9.6	0.9

Of the bulk cargo,70 percent was assumed to be small items and 30 percent was assumed to be large items (i.e., smaller and larger than pallet size, respectively). Each aircraft load of mixed cargo is to conform to a distribution of cargo types directly proportional to the total cargo moved.

Ideally, then, each load would contain the pounds of cargo given in Table XX.

TABLE XX

MIXED LOAD COMPOSITIONS

Aircraft	Pallets (lb)	POL (lb)	Bulk (lb)	Total (lb)
CV-2	3760	-	3530	7,290
CV-7	2980	4300	3150	10,430
10-Ton STOL	5700	8200	6060	19,960
CH-47	9800	2100	2100	14,000

However, it was found that if the ideal ratios were rigidly conformed to, unrealistic loads were produced; i.e., POL drums would be loaded half full. Therefore, actual loads were composed with the ideal distribution as a goal, but individual cargo weights were not varied beyond reasonable limits. This conflict between operational realism and consistency of analytical technique appeared occasionally but was reasonably resolved in all cases. The general objective was to maximize operational realism without compromising the analytical techniques. Only in the context of the weight, load compositions, and handling time problems can the rationale for a deterministic rather than a simulation approach be fully appreciated.

VEHICLE LOADS

Sets of type-loads were made up for each aircraft from the vehicles of the Airmobile Division. Because the aircraft varied in their ability to accept the vehicles, a check was first made to determine which of the vehicles would fit in each respective aircraft. Type-load sets were limited to only those vehicles transportable in the aircraft model chosen for the study.

Vehicle types with similar characteristics were combined to form one vehicle type. This was done to consolidate the number of type loads. Similar characteristics among vehicles in this case encompass vehicles with insignificant dimensional or weight differences and with similar

tiedown requirements resulting in similar loading and unloading times. An example of vehicles with similar characteristics would be the combination of trucks with winches and trucks without winches to form a single vehicle type.

The vehicle frequency distribution was determined for each aircraft by plotting the percent of a given type vehicle as a function of the cumulative percent of all vehicle types. These graphs are shown in Figures 30 through 32. Low frequency vehicle types were then eliminated to reduce the quantity of load types. Inclusion of the low frequency vehicles would have had an inconsequential effect on the final results.

Once the major vehicle types were known, loads were formed. These major vehicle types are combined to form loads with the following characteristics:

1. Floor space use is maximized.

2. The center of gravity of the load is within the center-of-gravity limits of the aircraft.

3. Vehicle net weight is less than the ACL.

4. Vehicle gross weight is equal to or exceeds the ACL.

The net weight of a vehicle is the curb weight of the vehicle; i.e., the vehicle is fueled with no crew or cargo. The gross weight is the net weight plus accompanying supplies and crew. Having the vehicle net weight below the ACL and the vehicle gross weight equal to or slightly above the ACL allows flexibility in substitution of cargo handling system weight for accompanying supplies on the vehicles. The weight of each cargo handling system can be offset by the removal of accompanying supplies from each load. The cargo removed from the vehicles is assumed to be diverted then to create additional bulk loads. The quantity of these loads is dependent upon the amount of supplies off-loaded from the vehicles. The consequence of adding cargo handling systems of varying weights can then be measured by the number or weight of additional bulk loads formed.

The type-loads formed using this methodology are illustrated in the appendix. It can be seen that some of the aircraft loads were still floor area limited (less than ACL) even when combining the gross weight of the vehicles with the weight of the cargo handling system. Vehicle loads for the CH-47 are the same as those for the CV-7 and are not repeated.

In load 21 (10-ton STOL), when the heavier cargo handling systems were used, the weight of the cargo handling system plus the net weight of the vehicles would have exceeded the allowable cargo load of the aircraft. To reduce the payload for these cases, the LTWPN carrier was removed

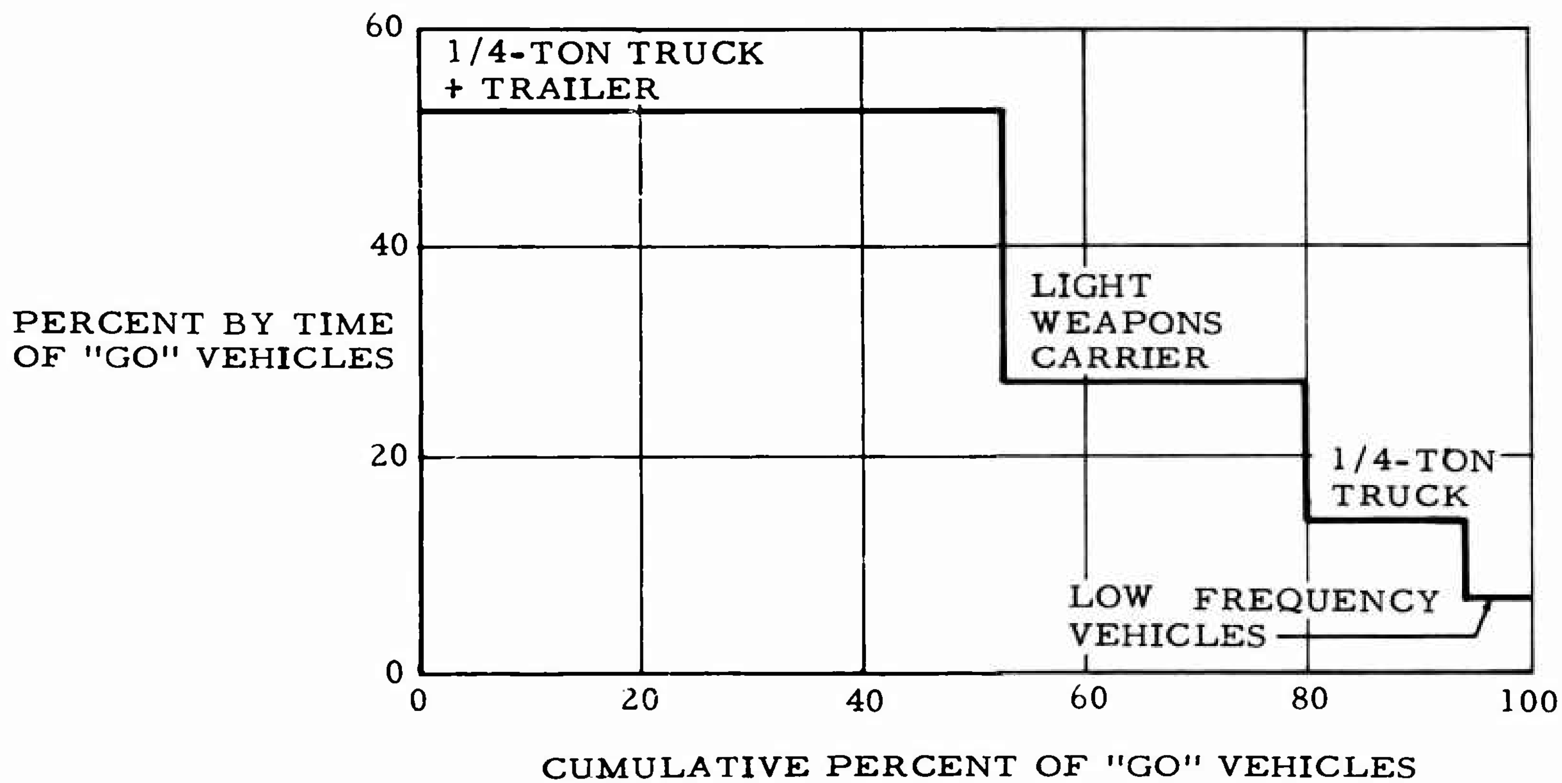


Figure 30. CV-2 Vehicle Frequency Distribution

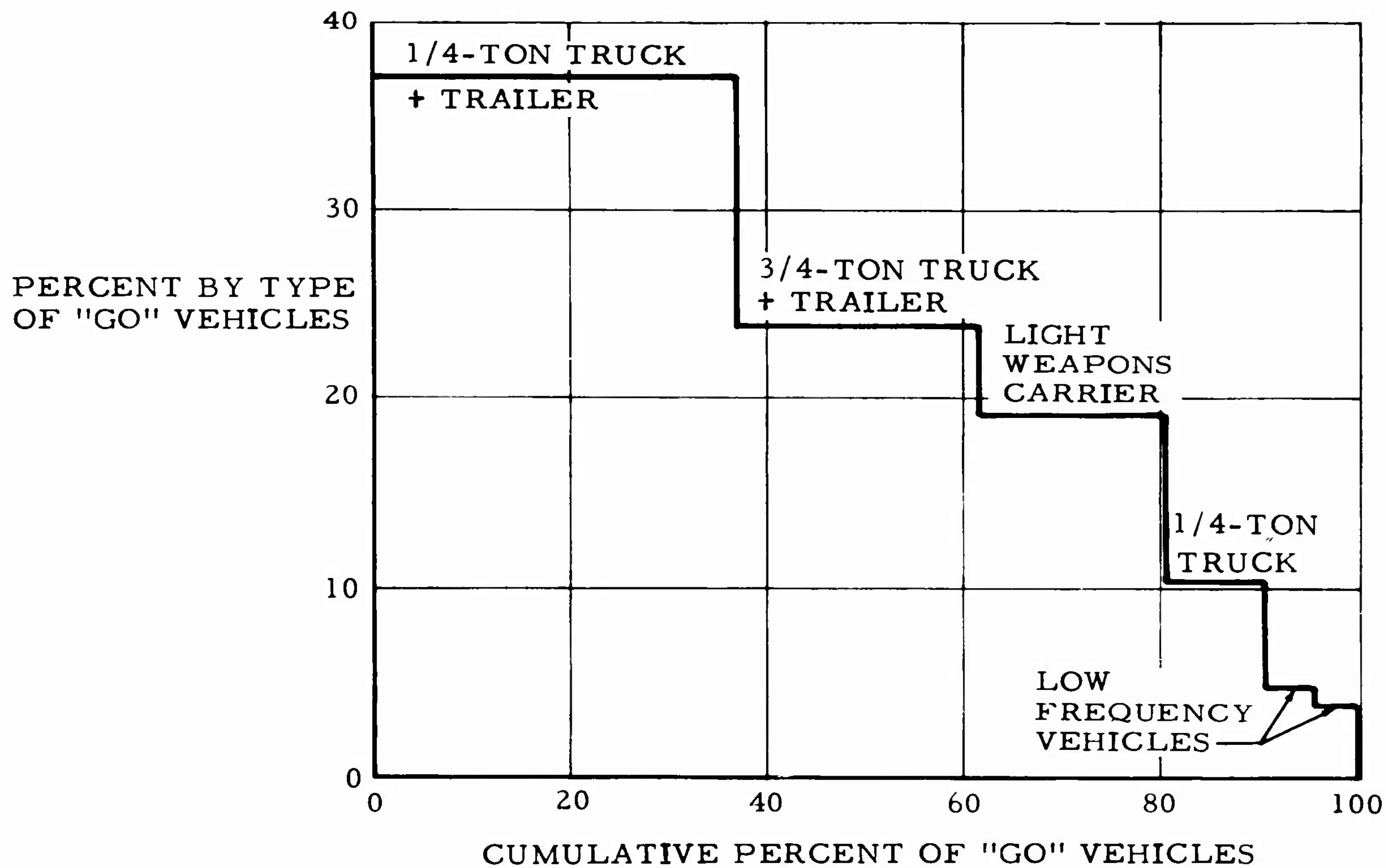


Figure 31. CV-7 and CH-47 Vehicle Frequency Distribution

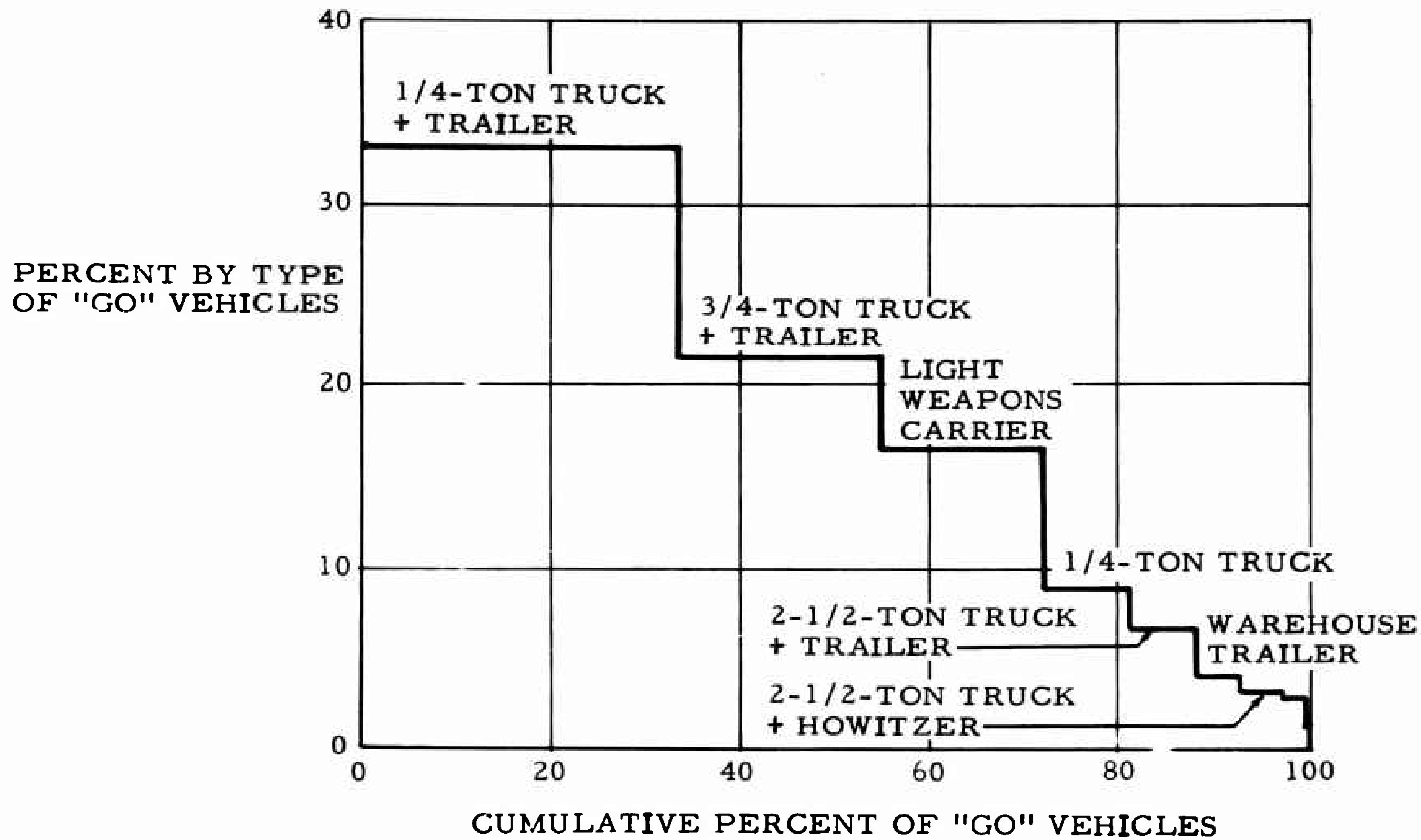


Figure 32. 10-Ton STOL Vehicle Frequency Distribution

and bulk supplies were substituted until the aircraft ACL was reached. The LTWPN carrier was then transferred to load 20 (10-ton STOL), which had space and payload available. The cargo that was bumped to accommodate the LTWPN carrier was then diverted to create additional vehicle bulk loads. This has little effect on the loading time of either load because this time is established in both loads by the time required to load the 2-1/2-ton truck which is contained in back of the above loads.

AIRDROP LOADS

The resupply of Army combat units requires the airdrop of POL (in 5-gallon cans), ammunition, and rations from fixed-wing aircraft. Two methods of packaging airdrop loads were considered: A-22 containers and pallets. For this study, pallets were selected because they are compatible with a majority of cargo handling systems being evaluated.

Systems 1 and 2 are inadequate for airdrop. System 1, containing no conveyors, has a coefficient of friction too high for rapid cargo extraction. System 2, containing low friction strips, has a lower coefficient of friction but lacks directional control because of the absence of buffer boards.

System 3, containing buffer boards, provides pallet guidance and protection for aircraft structure during extraction of palletized airdrop loads. System 3 would use a 15-foot extraction chute and G-12 cargo parachutes. Sequential extraction is accomplished on the 10-ton STOL because it is the only aircraft requiring more than one airdrop pallet to utilize all of the available payload. Extraction forces applied are approximately 1g.

System 4 (463L-type system) provides excellent airdrop capability for palletized loads because vertical and lateral restraint are provided by guide rail flanges until a fraction of a second before the load leaves the aircraft, and roller conveyors provide a low friction surface.

System 5, like the 463L system, provides airdrop capability for palletized loads because the guide rails provide vertical and lateral restraint during extraction and roller conveyors provide a low friction surface. Palletized airdrop loads are discharged by parachute extraction.

System 6 is considered to be unacceptable for airdrop unless provided with a boost system to eject cargo. Airdrop could not be accomplished by parachute extraction because of the high friction of the belt. If rapid acceleration of the belt was not accomplished, the aircraft stability would be endangered.

The CV-2 aircraft is capable of carrying 7132 pounds of cargo. When system, pallet, and parachute weights are added, the weight of delivered supply is as shown in Table XXI.

TABLE XXI

CV-2 AIRDROP LOADS

Cargo Handling System	Weight (lb)	Pallet and Tiedown Weight (lb)	Parachute* Weight (lb)	Delivered Supplies (lb)
3	499	300	392	5941
4	437	300	392	6003
5	886	300	392	5554

*Three G-12 cargo parachutes plus one 15-foot-diameter extraction parachute.

The airdrop pallet for the CV-2 would be a special width.

The CV-7 aircraft is capable of transporting 10,600 pounds of cargo. Permissible single item airdrop load is 7500 pounds, less load rigging weight. The amount of cargo which can be dropped from a CV-7 is shown in Table XXII.

TABLE XXII

CV-7 AIRDROP LOADS

Cargo Handling System	Weight (lb)	Pallet and Tiedown Weight (lb)	Parachute* Weight (lb)	Delivered Supplies (lb)
3	786	315	392	6793
4	520	315	392	6793
5	1356	315	392	6793

*Three G-12 cargo parachutes plus one 15-foot-diameter extraction parachute.

The 10-ton STOL, with a 20,000-pound payload would have the airdrop capacities shown in Table XXIII.

TABLE XXIII

10-TON STOL AIRDROP LOADS

Cargo Handling System	Weight (lb)	Pallet and* Tiedown Weight (lb)	Parachute** Weight (lb)	Delivered Supplies (lb)
3	976	630	1027	17,367
4	514	630	1027	17,829
5	1818	630	1027	16,525

*Two 463L pallets.
**Each pallet uses two G-11A cargo parachutes plus one 15-foot-diameter extraction parachute (parachute weight is approximately equal for either G-11A or G-12 parachute). Rate of descent is slower with G-11A's.

RETROGRADE LOADS

Retrograde cargo to be carried by the CV-2, CV-7, CH-47, and 10-ton STOL will vary with the magnitude of the war being fought and the intensity of fighting.

The retrograde cargo will consist of personnel in the form of litter cases, ambulatory cases, and healthy individuals in addition to cargo items such as collapsible fuel containers and repairable equipment.

Using the above assumptions, an approximate retrograde pattern (based on percent of cargo tonnage delivered) would consist of 15-percent general cargo and 35-percent personnel. This means that retrograde tonnage is a maximum of 50 percent of delivered tonnage. The general cargo, consisting of collapsed containers and repairable parts, would be returned as bulk cargo. Collapsed containers weighing 300 pounds can be loaded manually by four men. It is assumed that no retrograde cargo will be larger or heavier than the collapsed container.

The time required for loading of bulk retrograde cargo is roughly a proportional percent of the time required for loading a full load of bulk cargo. Restraint time for bulk cargo is not proportional to the load weight. This is because MC-1 tiedown devices are often used at a fraction of their capacity in small aircraft, and often the restraint pattern is determined by slip planes in cargo stacks. Using the above logic, loading

and restraining retrograde bulk cargo (about 15 percent of delivered cargo tonnage) will require approximately 50 percent of the time required for a full load.

To determine variations in retrograde cargo loading times related to aircraft and cargo handling systems, a representative cargo mix common to all aircraft should be used. The frequency at which specific repairable items are returned during wartime is quite uncertain. Some may be electronic components, some may be mechanical devices, and some may be supplies urgently needed elsewhere. However, it is assumed that 500-gallon containers will be used extensively and their return will be frequent. These containers are selected as general cargo for retrograde loads, since they represent the largest units of general cargo and will be most frequently transported.

The quantity of litter patients varies and is a result of the magnitude, severity, and success of military engagements. Ambulatory and healthy personnel as retrograde cargo will also vary with battle conditions. Litters present the greatest difficulty in loading retrograde cargo because they are not self-propelled and litter provisions form restrictions in the cargo compartment.

The type of retrograde cargo will often consist of one type of cargo. When there is a lull in combat activities, general cargo will probably be prevalent as retrograde cargo. If there is intensive military action, some aircraft may carry a full load of litter patients. With these variations in mind, a load containing litters, ambulatory patients, and collapsible fuel drums was selected because, although this specific load may never be carried, it will result in about the same retrograde cargo handling time as if each cargo was considered to be loaded separately.

Although collapsed fuel containers may not be transported at the same time as wounded personnel because of the fumes, they are considered as representative of any general cargo. With variations in both ambulatory and litter patients, a representative load should include all three types of retrograde cargo. The actual quantities of each cargo for each aircraft are shown in Table XXIV.

TABLE XXIV

RETROGRADE LOADS

	Containers		Litters		Ambulatory		
Aircraft	Qty	Wt (lb)	Qty	Wt (lb)	Qty	Wt (lb)	Total Weight (lb)
CV-2	1	300	6	1500	6	1500	3,300
CV-7	2	600	9	2250	9	2250	5,100
CH-47	2	600	12	3000	12	3000	6,600
10-Ton STOL	4	1200	18	4500	18	4500	10,200

CARGO HANDLING TIME

The degree of automation inherent in an aircraft cargo handling system has a great influence on loading crew manpower requirements and loading time, which in turn influence system effectiveness. The primary justifications for the higher degrees of automation are a reduction in load/unload time and a resultant decrease in aircraft turnaround time.

The method used to develop the load/unload time estimates was an incremental analysis of the time required to accomplish each function. Due consideration was given to the influence that different cargo handling systems have on loading and restraint.

The diagramming of the loading time is handled on "time-line sheets" which basically conform to standard industrial engineering practices (Figure 33). Each function is identified, and the time to accomplish the function is portrayed graphically in bar chart form. Using this method aids in visualization of time per function, summing functions, and problems encountered when two functions of different elapsed time are accomplished simultaneously and a start time for the third function is dependent on completion of either one or both previous functions.

Conditions for loading are considered to be optimum with personnel fully qualified and working at peak efficiency. These analyses covered the loading, restraining, releasing restraint, and unloading phases of cargo handling in four types of Army aircraft: the CV-2, CV-7, 10-ton STOL, and CH-47.

DETAIL OF APPROACH

Each cargo handling function was examined in detail, and simulated operations were conducted on paper to assess accurately the time consumed during each step.

Each time-line sheet in the study details cargo movement from its entry into the aircraft cargo compartment to its tiedown position and subsequent restraint. It then shows the time taken to release the restraint and move the cargo over the aircraft threshold. Time taken to position, activate and deactivate the moving equipment, and stow restraint devices is also detailed.

The type of aircraft and equipment used had a direct bearing on the number of men handling the cargo. An optimum crew size was established in each case to conduct each function with maximum efficiency. Maximum use was made of function overlap when two or more phases of the operation could be accomplished concurrently.

Each aircraft was analyzed with several loads utilizing six different cargo handling systems.

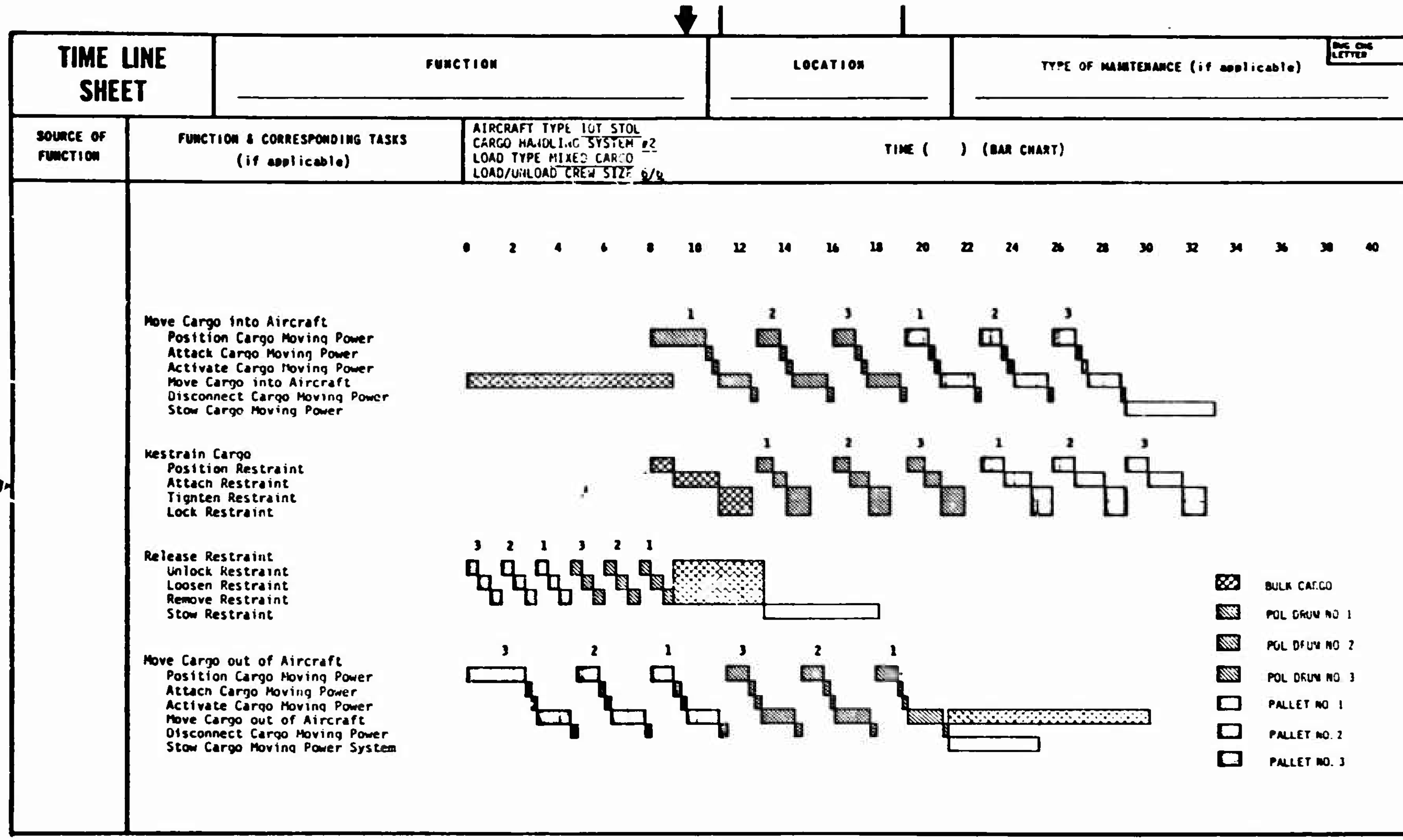


Figure 33. Time-Line Analysis

To maintain consistency throughout all functional analyses, the following standards and assumptions were established:

1. The winch, when used, will move cargo at the rate of 30 feet/minute.

2. Men can push palletized cargo at the rate of 30 feet/minute if rollers are installed in the aircraft.

3. An adequate number of tiedown fittings is available in each aircraft for the restraint of cargo. It was assumed that the aircraft tiedown pattern was compatible with the cargo being restrained. Detailed analysis of individual aircraft tiedown fitting patterns is beyond the scope of this study.

The figures in the appendix show the cargo loads used for the evaluation. Beneath each load is the time to load and unload that cargo load, excluding weight and balance time and retrograde cargo handling time. The payloads listed are net figures after special pallets, and restraint devices have been subtracted from the available aircraft payload.

WEIGHT AND BALANCE TIME

The complete evaluation was made, first with purely manual calculation of aircraft weight and balance, then with a fully automated weight and balance system in the aircraft.

For manual weight and balance, Form F (DD Form 365F, see Figure 34) is a summary of the actual disposition of the load in the helicopter or aircraft. It serves as a work sheet on which to record weight and balance calculations and any corrections that must be made to assure that the air vehicle will be within the weight and the center-of-gravity limits.

Form F is generally prepared in three steps, as follows:

1. Computation of total airplane weight and limitations (reference items 1 through 11 and Limitations, DD Form 365F).

2. Determination and internal distribution of allowable load (payload) by compartments (reference item 12, DD Form 365F).

3. Computation of takeoff center of gravity and estimated landing center of gravity (reference items 13 through 21, DD Form 365F).

NOTE: THIS TRANSPORT CLEARANCE FORM HAS RESULTED FROM A TRIPARTITE AGREEMENT AND NO FURTHER CH... MAY BE MADE TO IT WITHOUT PRIOR CONSIDERATION BY TRIPARTITE AUTHORITIES.

WEIGHT AND BALANCE CLEARANCE FORM F
TRANSPORT
(USE REVERSE FOR TACTICAL MISSIONS)

Cross Reference
RAF Form 2870
RCAF Form F 115 O
MOM 8-61 (0797)

FOR USE IN T. O. 1-1B-40 & AN 01-1B 40

DATE	AIRPLANE TYPE	FROM	HOME STATION
MISSION/TRIP/FLIGHT/NO.	SERIAL NO.	TO	PILOT

LIMITATIONS			
CONDITION	TAKEOFF	LANDING	LIMITING WING FUEL
[1] ALLOWABLE GROSS WEIGHT			
TOTAL AIRPLANE WEIGHT (*Ref. 11*)			
OPERATING WEIGHT PLUS ESTIMATED LANDING FUEL WEIGHT			
OPERATING WEIGHT (*Ref. 8*)			
ALLOWABLE LOAD (*Ref. 18*) (use *SMALLEST figure*)			
[2] PERMISSIBLE C. G. TAKEOFF	FROM	TO (% M.A.C. or IN.)	
[2] PERMISSIBLE C. G. LANDING	FROM	TO (% M.A.C. or IN.)	
[5] LANDING FUEL WEIGHT			

REF	ITEM	WEIGHT	[1] INDEX OR MOM/
1	BASIC AIRPLANE (*From Chart C*)		
2	OIL (Gal.)		
3	CREW (*No.*)		
4	CREW'S BAGGAGE		
5	STEWARD'S EQUIPMENT		
6	EMERGENCY EQUIPMENT		
7	EXTRA EQUIPMENT		
8	OPERATING WEIGHT		
9	TAKEOFF FUEL (Gal.)		
10	WATER INJ FLUID (Gal.)		
11	TOTAL AIRPLANE WEIGHT		

REMARKS

12 DISTRIBUTION OF ALLOWABLE LOAD (PAYLOAD)								
UPPER COMPARTMENTS				LOWER COMPARTMENTS				
COMPT	PASSENGERS NO.	PASSENGERS WEIGHT	CARGO	COMPT	PASSENGERS NO.	PASSENGERS WEIGHT	CARGO	
A								
B								
C								
D								
E								
F								
G								
H								
I								
J								
K								
L								
M								
N								
O								
P								
FWD	BELLY							
AFT	BELLY							

TOTAL FREIGHT	
TOTAL MAIL	
COMPUTER PLATE NUMBER (*If used*)	

[1] *Enter constant used.*
[2] *Enter values from current applicable T. O.*
[3] *Applicable to gross weight (Ref. 13).*
[4] *Applicable to gross weight (Ref. 18).*
[5] *Ref. 9 minus Ref. 17.*

CORRECTIONS (*Ref. 14*)			
COMPT	ITEM	CHANGES (+ or −) WEIGHT	[1] INDEX OR MOM/
TOTAL WEIGHT REMOVED		−	−
TOTAL WEIGHT ADDED		+	+
NET DIFFERENCE (*Ref. 14*)			

REF	ITEM	WEIGHT	INDEX OR MOM/
13	TAKEOFF CONDITION (*Uncorrected*)		
14	CORRECTIONS (*If required*)		
15	TAKEOFF CONDITION (*Corrected*)		
16	TAKEOFF C. G. IN % M. A. C. OR IN.		
17	LESS FUEL		
18	LESS AIR SUPPLY LOAD DROPPED		
19	MISC. VARIABLES		
20	ESTIMATED LANDING CONDITION		
21	ESTIMATED LANDING C. G. IN % M. A. C. OR IN.		

COMPUTED BY
SIGNATURE

WEIGHT AND BALANCE AUTHORITY
SIGNATURE

PILOT
SIGNATURE

DD FORM 1 SEPT 54 365F

Figure 34. Weight and Balance Clearance Form

Step one must be accomplished before loading can begin. This step is required to determine the actual allowable ACL for that particular mission. Step two must be accomplished either before or during the actual loading. Preliminary center-of-gravity checks are required to insure that the aircraft will be within center-of-gravity and weight limits when loading is completed. Step three will be accomplished after loading is complete.

With a known load, step two can be preplanned, and only checking during the loading will be required to insure that cargo is placed in the planned compartment.

Time required for completion of weight and balance will vary with the complexity of the load. Since the aircraft being used are relatively small and loads are preplanned, an average time of 5 minutes has been allowed for preparation of DD Form 365F, as step three is the only portion of the process that has direct bearing on the elapsed time required for loading.

The automated weight and balance system currently being developed for the C-130 aircraft by the National Water Lift Company, Kalamazoo, Michigan, computes the aircraft gross weight and center of gravity by using transducers in the landing gear and an analog computer onboard the aircraft. The actuation of two controls calculates the weight and the center of gravity of the aircraft and displays the center-of-gravity location in percent of MAC. In both cases the computation is made almost instantly, and the only time required is to record the result on the Form F. One-half minute is allowed to perform this complete operation on each flight.

The use of the automated weight and balance system does not preclude the necessity of planning the loads. The planning function, however, does not affect loading time, as it is assumed to be accomplished prior to aircraft arrival.

RETROGRADE CARGO LOADING TIME

Aircraft preparation required for transporting ambulatory or healthy personnel consists of unfolding stowed troop seats downward from the sides of the aircraft and fastening them to seat studs. Ambulatory or healthy personnel enter the aircraft single to triple file, dependent on the aircraft, and, walking at 30 feet/minute, can be secured in their seats in approximately 3 minutes.

Loading litter patients requires aircraft preparation by installing straps and floor supports. Litter supports can be installed by two men in 2 to 4 minutes. Some cargo systems have conveyors on the floor. Portions of these may require removal to provide adequate aisle space. The conveyors can be removed and stowed while other personnel are loading bulk cargo and installing the litter supports. Litter patients are brought into the aircraft single file (floor width of 6 feet) or double file (floor width of 8 feet). A

loading time of 3 minutes for each litter patient is based on carrying patients into position, securing litters to litter supports, and litter bearers exiting from the cargo compartment.

The sequence for loading retrograde cargo is general cargo, litters, and then ambulatory personnel. This sequence is desirable because the cargo is stowed forward of personnel in the cargo compartment for safety, and injured personnel spend a minimum of time in the aircraft.

In each aircraft the maximum crew size which could be effectively utilized in the available aisle space was used. This kept the retrograde load time to a minimum for each aircraft. A time-line analysis for the CV-7 retrograde cargo loading, where no conversion time of the cargo handling system is required, is shown on the left in Figure 35. A time-line analysis for the same load when the cargo handling system must be converted is shown on the right in the figure. In the latter case, two men are added to the loading crew, thus keeping the total time constant. Retrograde cargo handling time was 14 minutes for the CV-2, CV-7, and 10-ton STOL and 15 minutes for the CH-47. The manpower varied up to 25 percent, depending on the aircraft involved and whether any conveyors or rollers had to be removed from the aircraft floor. Table XXV gives the manpower used in each case.

TABLE XXV

RETROGRADE CARGO HANDLING MANPOWER

Aircraft Model	Approximate Retrograde Payload (lb)	All Systems With Vehicles, POL, or Mixed Cargo Carried on Outboard Portion of Cycle	Cargo Handling System (Pallets or Bulk Outboard)					
			1	2	3	4	5	6
CV-2	3,500	6	6	6	8	8	8	6
CV-7	5,000	8	8	8	10	10	10	8
CH-47	7,000	12	12	12	14	14	14	12
10-ton STOL	10,000	16	16	16	20	20	20	16

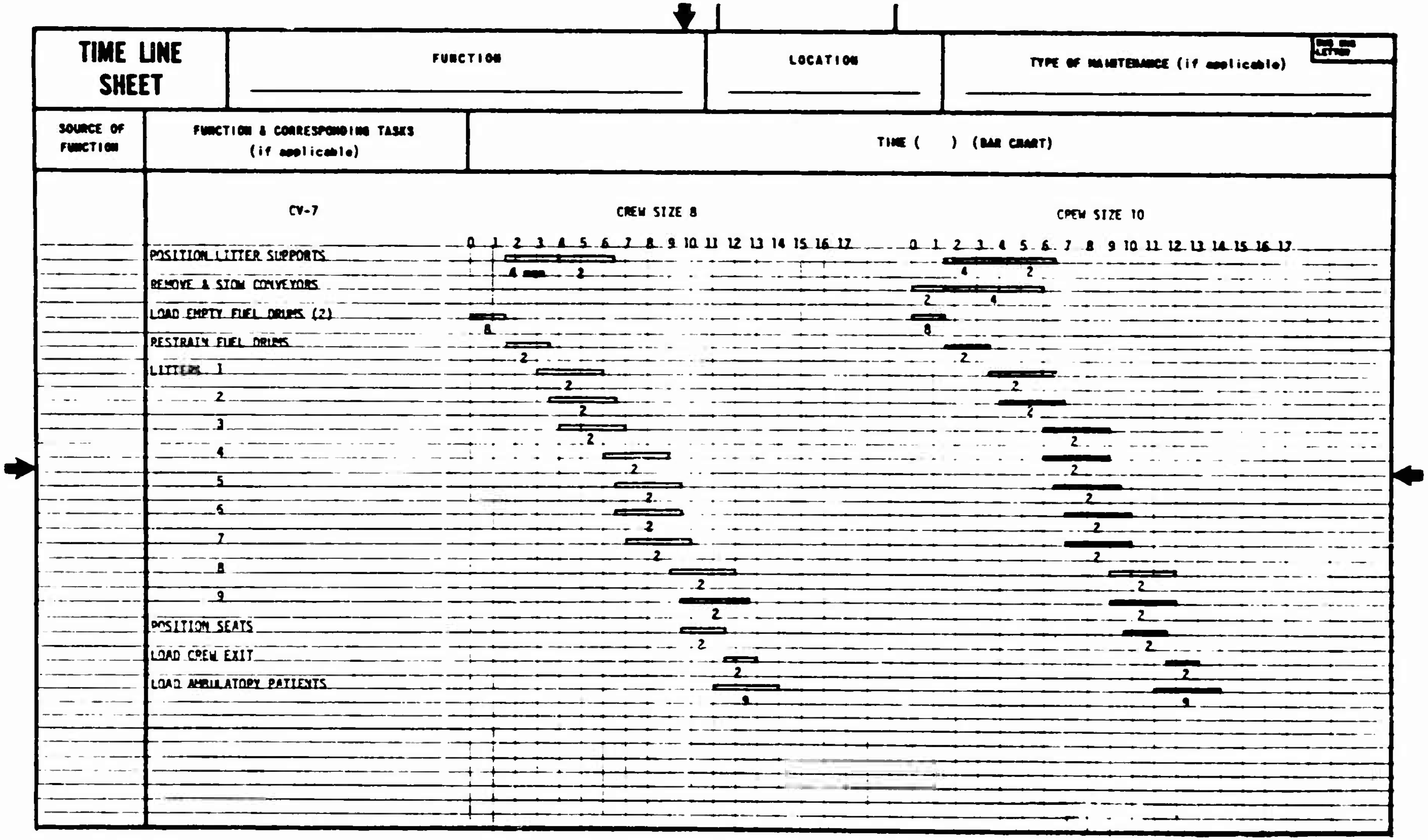


Figure 35. Retrograde Load Time-Line Analysis

MISSION COSTS AND COST FACTORS

The analytical costing methodology is summarized in Figure 36. This section presents the tabular summaries of cost input data required for the evaluation of automation within cargo delivery systems and their derivation. The primary categories of mission cost (investment, operating, losses) are derived for all required combinations of aircraft, weight and balance system, cargo handling system, mission, cargo type, and load type. The place of each costing subelement in determining total mission cost is shown in Figure 37.

The criteria followed in the accumulation and derivation of the data were as follows:

1. Consistency within like types of data.
2. Unclassified source data (if possible).
3. High degree of accuracy, at least relative accuracy within each like-type-data category.

All of the cost data inputs are summarized in five tables (Tables XXVI through XXX), as used in the analysis. Wherever a derivation is required, it is presented in its proper work and/or numerical form.

INVESTMENT COSTS

The investment cost of each cargo delivery system, including aircraft and cargo handling system, represents the total initial purchase cost of the system. The investment cost of each aircraft is comprised of its basic flyaway cost and its initial support cost. The unit investment costs of the CV-2B, CV-7A, and CH-47A were obtained from U. S. Army Project Offices; the 10-ton STOL investment cost was developed from data contained in Reference 4. The investment cost of each aircraft and cargo handling system was amortized over an expected useful life of 1825 operating days (5 operating-day years). This life expectancy value was based on military planning factors and engineering judgment. Each of the four aircraft was assumed to have an automated weight and balance subsystem in certain phases of the evaluation, and $7,500 was added to each cargo delivery system cost when appropriate. Each of the four aircraft was assumed to be in inventory, and thus no research and development cost was allocated to them.

The initial investment cost of each of the six cargo handling systems includes research and development costs, unit flyaway costs, and initial support costs. Cargo handling systems 1, 2, and 3 were assumed to be designed from off-the-shelf components; thus,no R&D cost was deemed necessary. The R&D

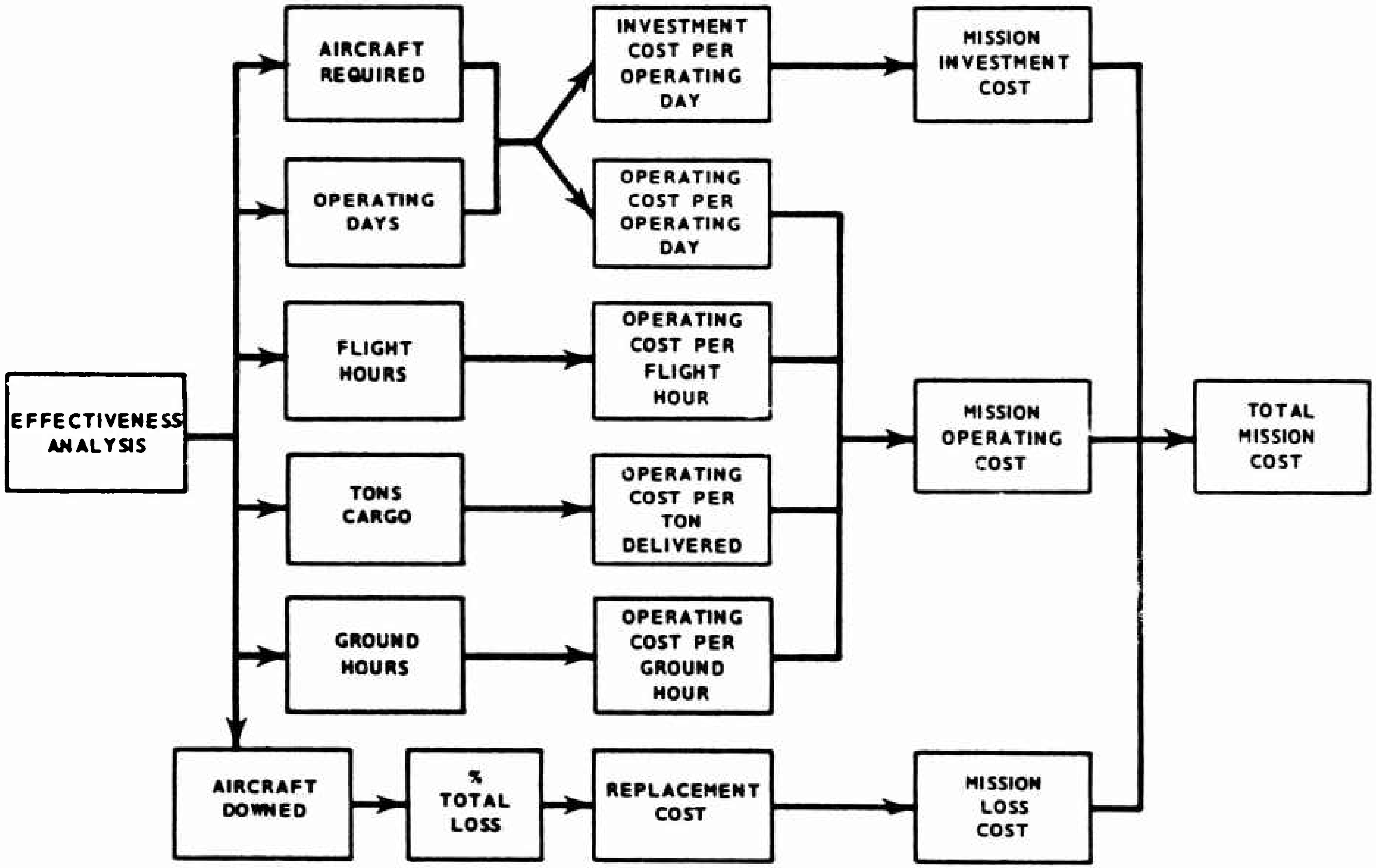


Figure 36. Flow of Cost Analysis

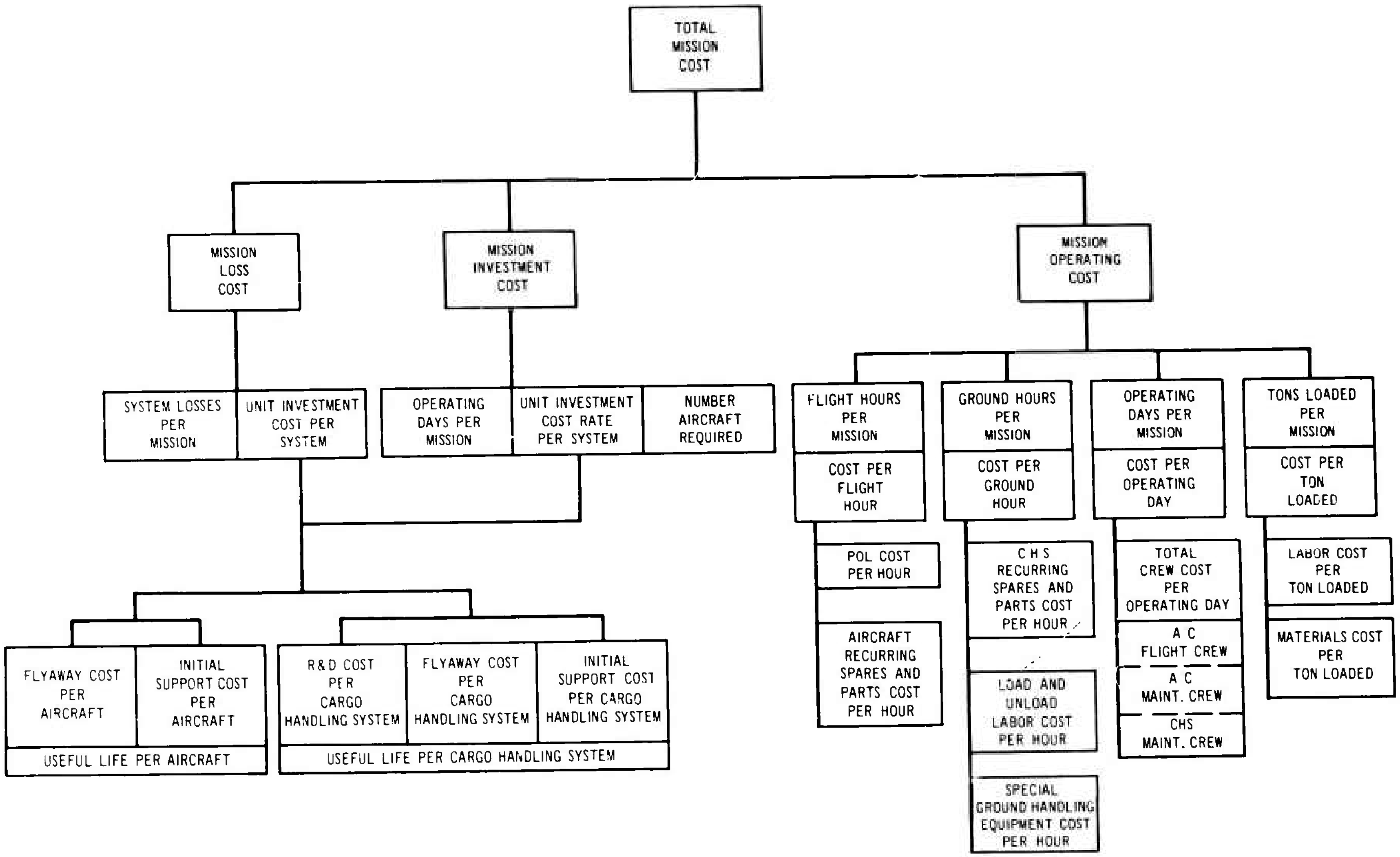


Figure 37. Total Mission Cost - Logic Flow

TABLE XXVI

INVESTMENT COSTS

Aircraft	CHS	Useful Life, Aircraft (Days)	Useful Life, CHS (Days)	Manual I_{ODA} ($/OD)	Weight & I_{ODC} ($/OD)	Balance I_D ($)	Automated I_{ODA} ($/OD)	Weight & I_{ODC} ($/OD)	Balance I_D ($)
CV-2B	1	1,825	1,825	469	0.065	855,119	472	0.065	862,619
	2	(5 yr)	(5 yr)		2.517	859,602		2.517	867,102
	3				2.530	859,626		2.530	867,126
	4				7.657	868,999		7.657	876,499
	5				5.842	865,680		5.842	873,180
	6				14.183	880,929		14.183	888,429
CV-7A	1			726	0.100	1,322,682	729	0.100	1,330,182
	2				2.615	1,327,280		2.615	1,334,780
	3				2.708	1,327,451		2.708	1,334,951
	4				8.547	1,338,125		8.547	1,345,625
	5				6.681	1,334,714		6.681	1,342,214
	6				15.945	1,351,649		15.945	1,359,149
10-Ton STOL	1			1,167	0.102	2,130,254	1,170	0.102	2,137,754
	2				2.615	2,135,106		2.615	2,142,606
	3				2.720	2,135,166		2.720	2,142,666
	4				8.731	2,145,492		8.731	2,152,992
	5				6.716	2,143,057		6.716	2,150,557
	6				16.005	2,164,202		16.005	2,171,702
CH-47A	1			894	0.139	1,630,886	897	0.139	1,638,386
	2				2.793	1,634,780		2.793	1,642,280
	3				2.826	1,634,972		2.826	1,642,472
	4				8.474	1,645,961		8.474	1,653,461
	5				7.142	1,642,277		7.142	1,649,777
	6				18.708	1,659,259		18.708	1,666,759

TABLE XXVII

OPERATING COST PER FLIGHT HOUR

Aircraft	CHS	A/C Recurring Spares/Parts Cost ($/Flt Hr)	POL Cost ($/Flt Hr) Airland Mode	POL Cost ($/Flt Hr) Airdrop Mode	O_{FH} ($/Flt Hr) Airland Mode	O_{FH} ($/Flt Hr) Airdrop Mode
CV-2B	1	xxx[1]	xxx	xxxx	218	213
	2					
	3					
	4					
	5					
	6					
CV-7A	1	xxx	xxx	xxxx	244	243
	2					
	3					
	4					
	5					
	6					
10-Ton STOL	1	xxx	xxx	xxxx	398	417
	2					
	3					
	4					
	5					
	6					
CH-47A	1	xxx	xxx		247	
	2					
	3					
	4			(No Mission)		(No Mission)
	5					
	6					

(1) Omitted, pending declassification

TABLE XXVIII

OPERATING COST PER GROUND HOUR

Aircraft	Generic Cargo Type (Y)	Operating Cost Per Ground Hour - O_{GH} CHS 1 ($/Hr)	CHS 2 ($/Hr)	CHS 3 ($/Hr)	CHS 4 ($/Hr)	CHS 5 ($/Hr)	CHS 6 ($/Hr)
CV-2B	1	6.85[1]	5.79	8.74	10.50	10.86	8.63
	2	10.25	10.43	11.29	11.47	11.43	8.46
	3	8.30	8.30	8.30	8.30	8.30	8.30
	4	6.85	6.54	9.04	9.96	10.20	8.83
	5	6.20	6.22	6.24	6.32	6.28	8.22
	6	7.60	7.62	7.64	7.72	7.68	7.34
CV-7A	1	7.88	6.71	12.08	12.36	13.13	10.68
	2	11.26	11.26	12.21	11.26	13.34	10.42
	3	10.81	10.81	10.81	10.81	10.81	10.81
	4	9.08	9.56	8.29	8.39	8.82	10.14
	5	9.06	9.07	10.54	9.19	9.17	8.14
	6	9.97	9.92	9.94	10.04	10.52	9.70
10-Ton STOL	1	15.40	11.33	20.15	24.93	24.06	20.23
	2	13.88	13.12	15.24	14.15	15.36	18.85
	3	21.60	21.60	21.60	21.60	21.60	21.60
	4	12.95	13.30	11.66	11.75	12.96	16.95
	5	16.50	16.52	16.29	16.63	16.61	18.33
	6	16.80	16.82	16.84	16.93	18.41	17.66
CH-47A	1	10.54	8.59	14.02	15.28	17.67	14.41
	2	15.10	15.12	14.12	14.22	14.24	15.83
	3	16.20	16.20	16.20	16.20	16.20	16.20
	4	10.55	11.97	10.56	10.66	11.32	14.10
	5	11.90	11.92	12.24	12.04	12.00	12.62
	6	13.60	13.62	13.64	13.74	14.50	14.19

(1) Values shown are weighted averages for each cargo type

TABLE XXIX

OPERATING COST PER OPERATING DAY

Aircraft	CHS	Operating Cost Per Operating Day: Cost Per Flight Crew ($/Day)	Cost Per A/C Maint Crew ($/Day)	Cost Per CHS Maint Crew ($/Day)	O_{OD} ($/Day)
CV-2B	1	63	413	0	476
	2			0	476
	3			0	476
	4			14	490
	5			14	490
	6			28	504
CV-7A	1	63	327	0	390
	2			0	390
	3			0	390
	4			15	405
	5			15	405
	6			29	419
10-Ton STOL	1	63	525	0	589
	2			0	589
	3			0	589
	4			14	603
	5			14	603
	6			29	618
CH-47A	1	63	525	0	589
	2			0	589
	3			0	589
	4			14	603
	5			14	603
	6			29	618

TABLE XXX

OPERATING COST PER TON LOADED

Aircraft	CHS	Operating Cost Per Ton Loaded - O_{TL} Mission A Pallets Airland ($/Ton)	Mission B Pallets Airland ($/Ton)	Daily Resupply Missions A & B Airdrop ($/Ton)
CV-2B	1	- (1)	-	-
	2	-	-	-
	3	-	-	780.00
	4	15.00(2)	10.40	715.00
	5	13.00(2)	11.00	765.00
	6	-	-	-
CV-7A	1	-	-	-
	2	-	-	-
	3	-	-	794.00
	4	11.00	8.80	794.00
	5	12.00	10.00	794.00
	6	-	-	-
10-STOL	1	-	-	-
	2	-	-	-
	3	-	-	704.00
	4	10.00	9.00	668.00
	5	11.00	9.70	723.00
	6	-	-	-
CH-47A	1	-	-	
	2	-	-	
	3	-	-	(No Mission)
	4	8.00	6.70	
	5	8.50	7.10	
	6	-	-	

(1) No costs for CHS indicated (-).

(2) For CV-2B, CHS 4 and 5: costs also apply for 500-gallon fuel drums.

cost of systems 4, 5. and 6 was estimated based on their relative complexities. Production of 200 units was assumed. The unit (flyaway) cost of each cargo handling system was estimated from relatively detailed contractor data, as were their respective initial support costs. The various combinations of investment costs utilized in the cost analysis are presented in Table XXVI.

Sample Calculation:

- Aircraft - CV-7A
- CHS - Rollers and guide rails with integral latching
- Manual weight and balance system
- Unit investment cost per aircraft - $1,322,500
- Unit investment cost per CHS - $15, 625

I_D = $1,322,500 + $15,625 = $1,338,125

I_{ODA} = $1,322,500 ÷ 1,825 = $726 per operating day

I_{ODC} = $15,625 ÷ 1,825 = $8.55 per operating day

The mission loss cost is calculated once I_D has been determined, and is dependent on the total delivery systems downed per mission, the percent of the downed delivery systems that are total losses, and the total investment cost per delivery system (I_D). For example,

- Aircraft - CV-7A
- CHS - Rollers and guide rails with integral latches
- Manual weight and balance system
- I_D = $1,338,125 (as previously calculated)
- Aircraft lost per mission = 0.205 (calculated)
- Percent of downed aircraft totally lost (F) = 0.48

Mission loss cost (L_T) = 0.205 × 0.48 × $1,338,135 = $132,788

OPERATING COSTS

The mission operating cost is comprised of four major factors:

1. Operating cost per flight hour.
2. Operating cost per ground hour.
3. Operating cost per operating day.
4. Operating cost per ton loaded.

The interrelationship of these items, their subelements, and the evolution of mission operating cost is shown in Figure 36. The cost building blocks will be discussed in this section, and appropriate examples will be given.

Operating cost per flight hour (O_{FH}) is the cost per flight hour directly attributable to the operation of the aircraft itself; that is, the sum cost of the POL and spares and/or parts consumed during the time the aircraft actually operates. O_{FH} is dependent on mission mode (airland or airdrop), since the average hourly mission fuel consumption is a function of mission mode. Table XXVII presents the total operating cost per flight hour for each delivery system configuration. The aircraft recurring spares/parts cost for the CV-2B, CV-7A, and CH-47A was obtained from Reference 11, page A-5; the 10-ton STOL was derived from the composite aircraft presented in References 4, 11, and 13. Because of an inadvertent over-classification on the part of the authors of Reference 11, only the total operating cost per flight hour is shown to keep this section unclassified.

Operating cost per ground hour (O_{GH}) consists of the cost of the labor to load and unload the cargo (both primary and retrograde), the recurring spares/parts cost of the cargo handling system, and the prorated cost (per hour) of any special ground handling equipment required in the cargo handling phase. The labor cost constitutes the greatest portion of the total operating cost per ground hour.

The loading/unloading time-line analyses for all types and loads of cargo were utilized to obtain the average weighted man-hours expended for each combination of aircraft, cargo handling system, mission, and cargo type. A labor rate of $1.35/man-hour was used in the calculation of the costs.

The recurring parts/spares cost per cargo handling system was estimated at a fixed percentage of the initial cost on an annual basis, then prorated on an hourly basis over 2,190 hours per year (equivalent to 6 using hours per operating day).

One special piece of ground handling equipment was estimated to be required per aircraft and was amortized over a 5-year 12-hour-per-day

lifetime (21,900 hours). The unit cost of this equipment was obtained from contractor documents.

The composite operating cost per ground hour is presented in Table XXVIII for each aircraft, cargo handling system, and generic cargo type.

Operating cost per operating day (O_{OD}) consists of the daily pay and allowances of the flight crew, aircraft maintenance crew (direct and indirect personnel), and cargo handling system special maintenance personnel (if any). The total operating personnel pay and allowances per operating day are "charged against the mission" whether utilized or not.

The manning requirements and respective costs were estimated to be as follows:

Flight Crew	Three per aircraft at $7,771 per man per year, including flight pay. (Based on two W-1 and one E-5 category personnel per crew, per Ref 10.)
Maintenance Crew	For aircraft only: CV-2B, 29; CV-7A, 23; 10-ton STOL; and CH-47A, 37. For cargo handling system only: CHS 1, 2, and 3 = 0; CHS 4 = 1; CHS 5 and 6 = 2. Average pay and allowances: $5,138 per man per year.

The flight crew (less manning factor) and the aircraft maintenance crew of the CV-2B, CV-7A, and the CH-47A were obtained from Reference 11, page A-10. The 10-ton STOL was assumed to have the same personnel allocation as the CH-47A.

<u>Sample Calculation:</u>

- Aircraft - CV-7A
- CHS - Rollers and guide rails with integral latching
- $O_{OD} = [(3)(\$7771) + 23(\$5138) + (1)(\$5138)] \div 365 = \$405$

The estimated operating cost per operating day allocated by type of crew is shown in Table XXIX. Any apparent discontinuities are due to rounding.

Operating cost per ton loaded (O_{TL}) consists of the cost of labor and materials expended in the preparation of cargo to be delivered and will be applied to both primary and retrograde missions. It will vary with type of

cargo handling system, type of mission, and type of aircraft, as shown in Table XXX. The labor cost (at $1.35 per man-hour) constitutes a minute fraction of the total for all cases considered, with the higher costs of the airdrop missions being primarily attributable to the cost of parachutes. For Mission A, the total cost per ton loaded was determined by weighing the total costs for each pallet load type by the tonnage delivered to derive a composite cost factor. Since Mission B has only one load type, no composite derivation procedure was necessary. Only one specific cargo type (pallets) was estimated to require special preparation costs; the other cargo types required no special operating cost expense.

All of the cost factors developed are extremely sensitive to the data sources and the credibility of these sources. It should be emphasized that the costs derived herein were developed in the manner indicated solely for the purpose of evaluating, on a mission cost basis, the effects of automation within cargo delivery systems for specific missions (radius, environment, combat unit, etc.). If and when these delivery systems are analyzed on higher levels within the cost cone, their composition and aggregation may change considerably.

ANALYSIS OF RESULTS

The results of the evaluation of the six cargo handling systems illustrated in Figure 38 are presented in this section. Each aircraft is discussed for each of the evaluation missions. The three general missions are:

1. Airland resupply mission.

2. Deployment mission.

3. Airdrop resupply mission.

The two resupply missions included both airland and airdrop delivery.

Mission A consists of the delivery of the daily resupply required to sustain an Air Assault Division in a combat operation. Most of the daily requirement is delivered by airlanding, with a small portion delivered by airdrop.

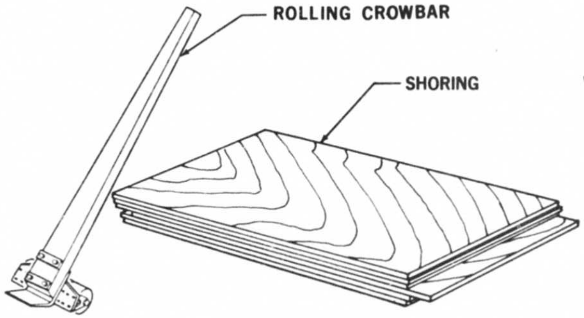
Mission B consists of the delivery of the daily resupply required to sustain the forward elements (approximately 20 percent of the total division) of a ROAD Infantry Division in a combat operation. As with Mission A, the delivery is split between airland and airdrop, with airland meeting the major requirements. The distribution of cargo by type for the resupply missions is shown in Figure 39.

The deployment mission consists of the delivery by airlanding of the vehicles and men of an Airmobile division. In each specific aircraft there are payload and size limitations which restrict the number of vehicles that will fit into the aircraft. This restriction is apparent if comparisons are made between the different aircraft for the deployment mission. The total number of aircraft will be larger for the bigger, higher payload aircraft. This occurs because the larger aircraft are capable of transporting a larger percentage of the vehicles of the division.

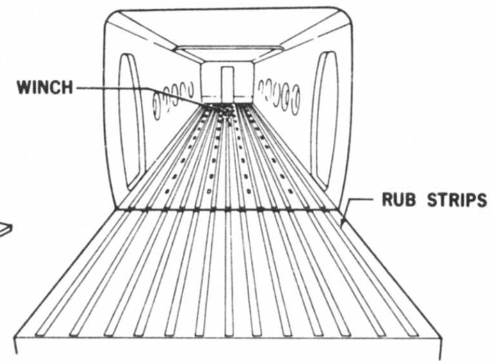
The evaluation included the effects of an automated weight and balance system. The results of that portion of the study follow the discussion of the aircraft studied.

CV-2 CARIBOU

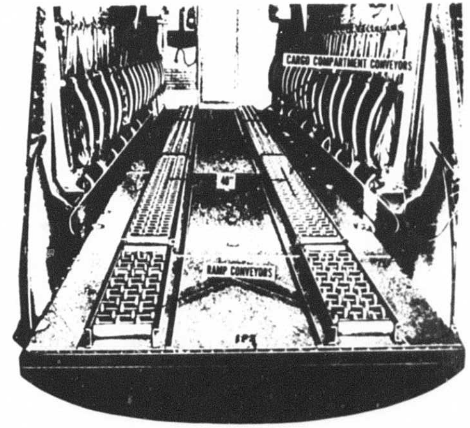
The results of the airland portion of the resupply missions are shown in Figures 40 and 41 and in Tables XXXI and XXXII. Figure 40 shows the effectiveness and cost trends as the degree of cargo handling system automation increases. For the CV-2 aircraft (payload 7287 pounds for 100-nautical-mile-radius mission), effectiveness decreased and cost increased as the degree of automation increased, for both resupply missions. The decrease in effectiveness is slight and at a relatively constant rate for



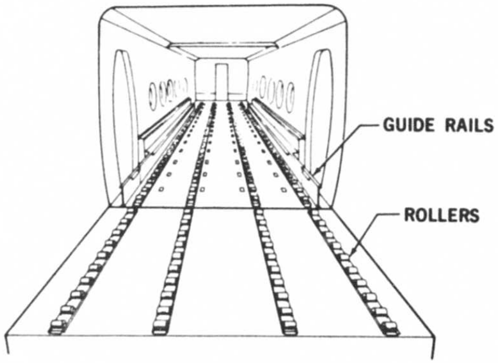
MANUAL W/TIEDOWN STRAPS
System 1



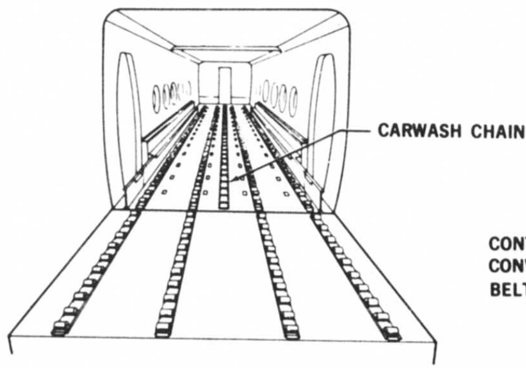
WINCH AND RUB STRIPS W/TIEDOWN STRAPS
System 2



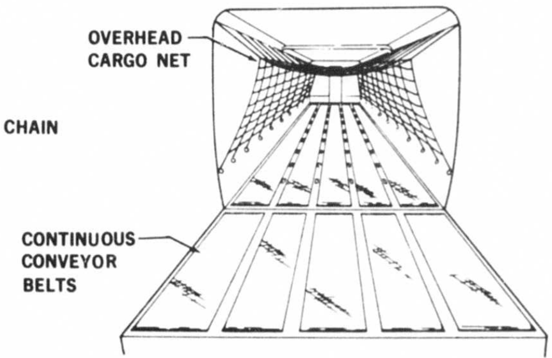
SKATE WHEEL CONVEYORS AND BUFFER BOARDS W/TIEDOWN STRAPS
System 3



ROLLERS, RAILS AND LATCHES
System 4



ROLLERS, RAILS AND CARWASH CHAIN
System 5



FULL WIDTH CONVEYOR BELT AND OVERHEAD NETS
System 6

Figure 38. Systems Evaluated

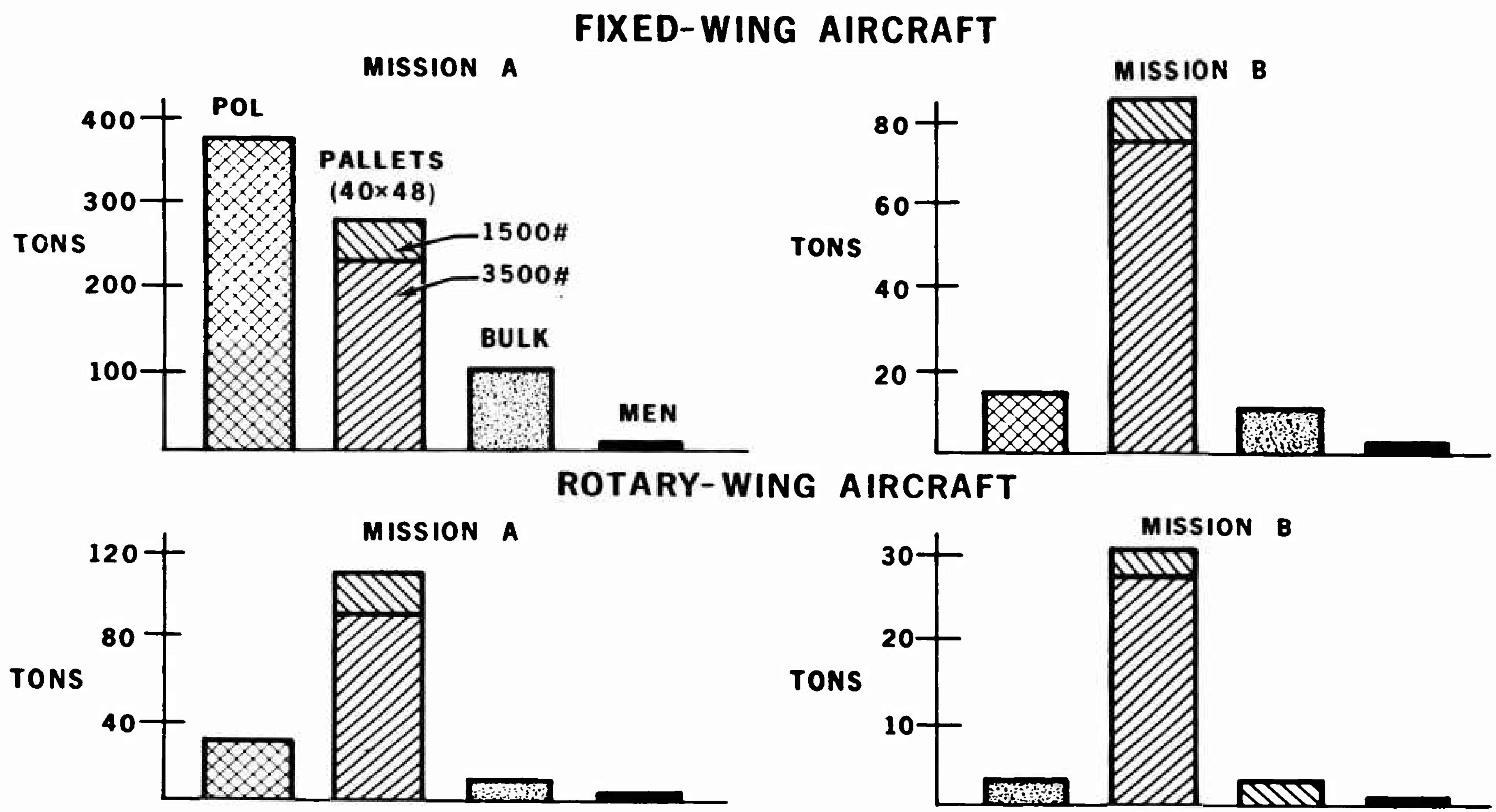


Figure 39. Mission Cargo Composition

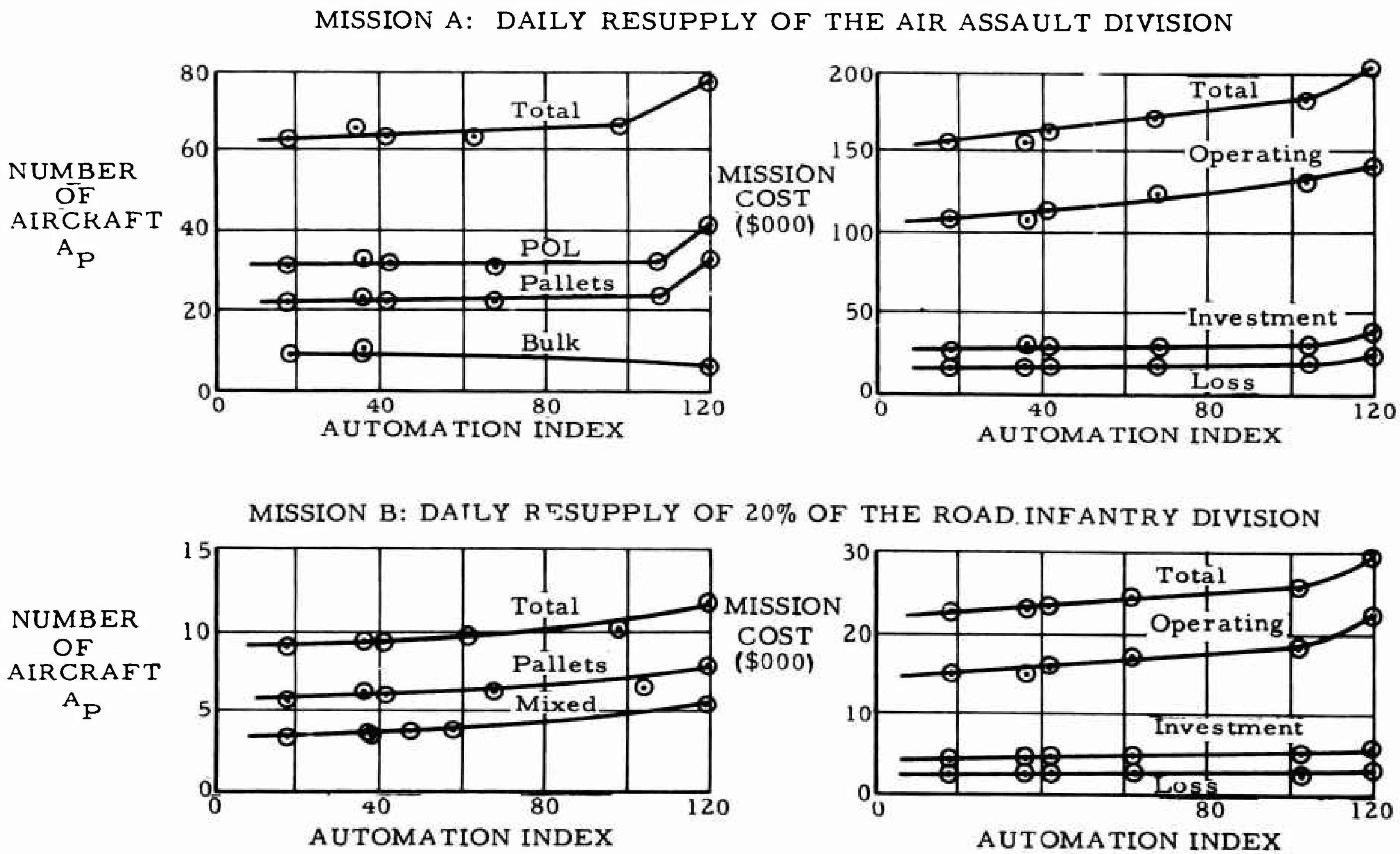


Figure 40. CV-2; Airland Resupply Missions; Effectiveness and Cost Trends as the Degree of Cargo Handling System Automation Increases

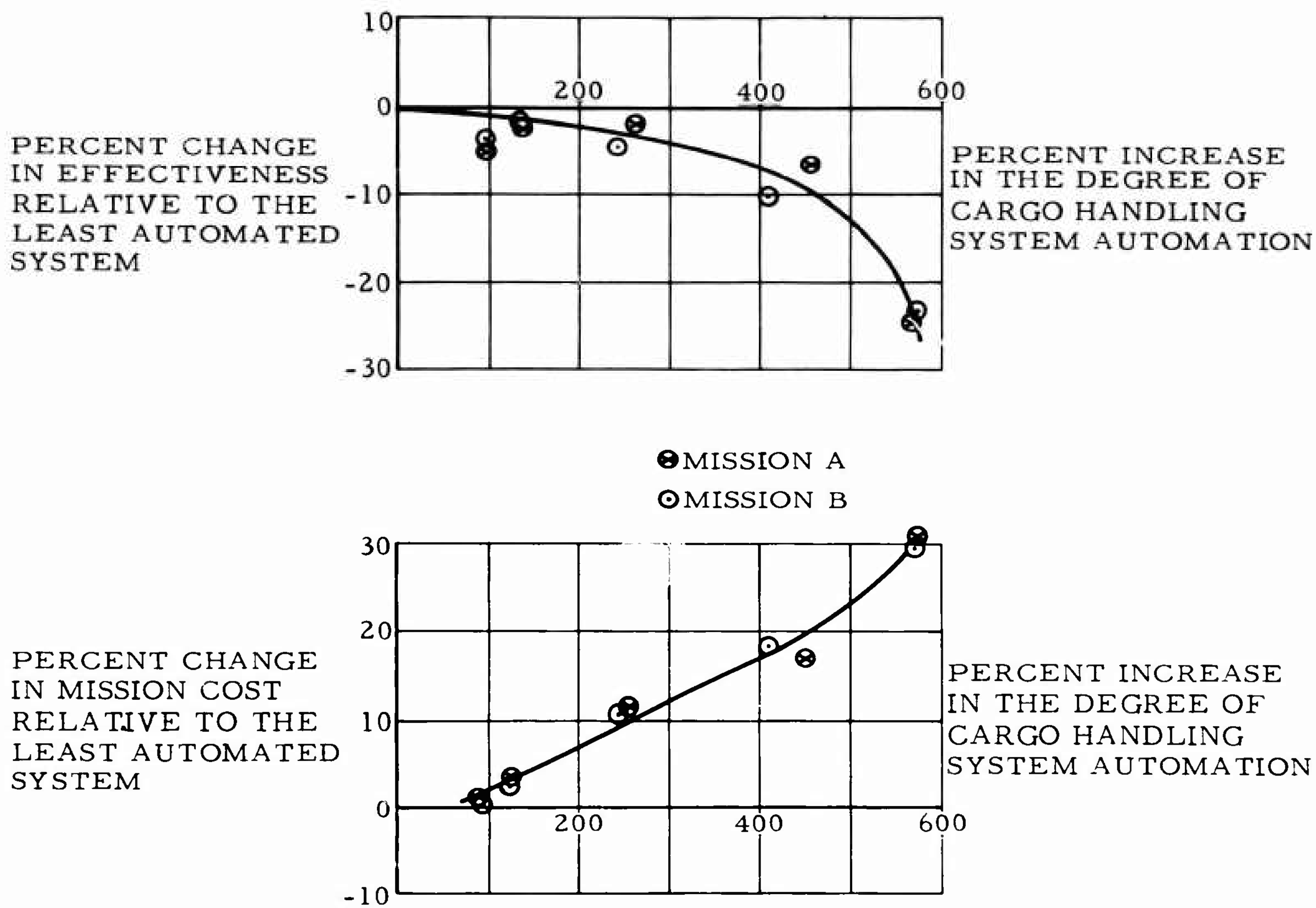


Figure 41. CV-2; Airland Resupply Missions; Percent Change in Effectiveness and Cost as the Degree of Cargo Handling System Automation Increases

TABLE XXXI

CV-2; AIRLAND DAILY RESUPPLY OF AIR ASSAULT DIVISION (MISSION A); MANUAL WEIGHT AND BALANCE

Cargo Handling System	1	2	3	4	5	6
Composite Automation Index	18.0	35.8	41.1	63.8	98.8	119.2
% Increase in Automation Index*	0	98.9	128.0	254.4	448.9	562.2
Total Number Aircraft Required	62.51	65.13	63.64	63.24	66.33	77.55
% Change in Effectiveness*	0	-4.19	-1.81	-1.17	-6.11	-24.06
Total Mission Cost ($000)	155.8	157.2	161.6	173.6	182.2	204.1
% Change in Cost*	0	+0.82	+3.62	+11.38	+16.85	+30.93
Aircraft Required by Cargo Type**						
Pallets (268 tons)	21.74	23.08	21.94	22.48	23.68	28.85
Bulk (88 tons)	8.96	8.81	9.03	9.12	9.60	7.00
Men (5.4 tons)	0.41	0.43	0.48	0.44	0.48	0.62
POL (382 tons)	31.40	32.81	32.19	31.19	32.56	41.08
Cost ($000) Breakdown						
Operating	109.0	109.2	113.2	124.7	130.7	142.0
Investment	29.3	30.6	30.0	30.1	31.5	38.9
Loss Cost	17.5	17.4	18.4	18.8	20.0	23.2

*All percentage changes are relative to the values obtained for the least automated cargo handling system.

**Corresponding automation indexes given on page 73.

TABLE XXXII

CV-2; AIRLAND DAILY RESUPPLY OF FORWARD ELEMENTS OF ROAD INFANTRY DIVISION (MISSION B); MANUAL WEIGHT AND BALANCE

Cargo Handling System	1	2	3	4	5	6
Composite Automation Index	18.0	36.3	41.1	61.7	92.9	120.0
% Increase in Automation Index*	0	102.	128.0	243.	416.	567.
Total Number Aircraft Required	9.35	9.68	9.45	9.75	10.30	11.55
% Change in Effectiveness	0	-3.53	-1.07	-4.28	-10.16	-23.53
Total Mission Cost ($000)	22.61	22.77	23.33	25.13	26.70	29.35
% Change in Cost	0	+0.71	+3.18	+11.15	+18.09	+29.81
Aircraft Required by Cargo Type						
Pallets (75 tons)	5.99	6.26	6.13	6.29	6.61	8.05
Mixed (32.5 tons)	3.35	3.42	3.32	3.46	3.69	3.49
Cost ($000) Breakdown						
Operating	15.73	15.73	16.26	17.75	18.90	20.42
Investment	4.38	4.56	4.45	4.65	4.89	5.58
Loss Cost	2.50	2.48	2.61	2.73	2.91	3.35

*All percentage changes are relative to the values obtained for the least automated cargo handling system.

automation indexes up to about 70. After an automation index of about 70, the effectiveness deteriorates at an increasing rate. The cost increases at a rapid and relatively constant rate up to an automation index of about 100 and then increases even more rapidly. The cause of these trends is due to (1) the aircraft having a small payload and (2) cargo handling time being small in comparison to the total cycle time due to the slow speed of the aircraft (block speed of 153 knots for 100-nautical-mile radius). Because of this, the weight of the cargo handling system (which is deducted from payload) has a detrimental effect which overbalances the savings realized by decreasing cargo handling time. For example, with palletized cargo, cargo handling system 6 causes a 25-percent decrease in payload capacity, a 68-percent decrease in the total cargo handling time, but only a 5-percent decrease in mission cycle time relative to the manual base case, system 1.

The cost curve of Figure 40 shows the total mission cost and the incremental costs plotted against the composite automation index. For the resupply mission, operating cost is about 70 percent of the total cost, with investment cost being about 20 percent, and loss cost being about 10 percent.

The trend plot shown in Figure 40 appears to be a fairly flat curve which tends to cloud the actual significance of the results. Figure 41 is a plot of the percent changes in effectiveness and cost (relative to the least automated system) as the degree of cargo handling system automation increases relative to the manual system with an automation index of 18. This curve more clearly depicts the result of the analysis. All percentage changes are calculated as shown below:

$$\% \text{ Change} = 100 \times \frac{\text{System "X" Value - Manual Value}}{\text{Manual Value}}$$

Table XXXIII and Figure 42 show the results of the analysis for the deployment mission. The first chart of Figure 42 shows the composite automation index (made up of the automation index for men and for vehicles and weighted by the relative quantity of each). As the automation index did not vary significantly, the bar chart technique was used to show the results. Very small effectiveness differences occur through cargo handling system 4 because the aircraft is volume limited when transporting vehicles except at high automation indexes. Although the overall effectiveness is about the same for system 5, it is noteworthy that the number of aircraft required for transporting vehicles decreases and the number required for transporting men increases. This is because system 5 decreases the cycle time for vehicles by simplifying the restraint, but the gain is offset by the increase in system weight which makes the carrying of men payload limited (payload all used with seats remaining). Therefore, additional trips must be made to transport all of the men. The same situation exists in system 6 except that the cargo system weight is much higher, causing the changes shown. For all systems, the operating cost is the largest portion of the total mission cost, about 70 percent. Total mission cost varies only slightly for all systems

TABLE XXXIII

CV-2; DEPLOYMENT OF AIR TRANSPORTABLE ELEMENTS OF AIRMOBILE DIVISION (MISSION A); MANUAL WEIGHT AND BALANCE

Cargo Handling System	1	2	3	4	5	6
Composite Automation Index	12.0	17.	17.	17.	35.2	101.3
% Increase in Automation Index*	0	42.	42.	42.	193.	744.
Total Number Aircraft Required	192.17	192.17	193.01	193.05	192.13	224.71
% Change in Effectiveness	0	0	-0.44	-0.46	+0.02	-16.93
Total Mission Cost ($000)	497.0	497.8	500.1	504.5	508.2	572.3
% Change in Cost	0	+0.16	+0.63	+1.51	+2.24	+15.14
Aircraft Required by Cargo Type						
Men (334 tons)	25.45	25.45	26.29	26.32	29.42	36.49
Vehicles (1589 tons)	166.72	166.72	166.72	166.72	162.70	188.22
Cost ($000) Breakdown						
Operating	349.6	349.6	351.3	354.0	357.7	398.4
Investment	90.1	90.6	91.0	92.0	91.2	108.5
Loss Cost	57.3	57.6	57.9	58.5	59.3	65.4

*All percentage changes are relative to the values obtained for the least automated cargo handling system.

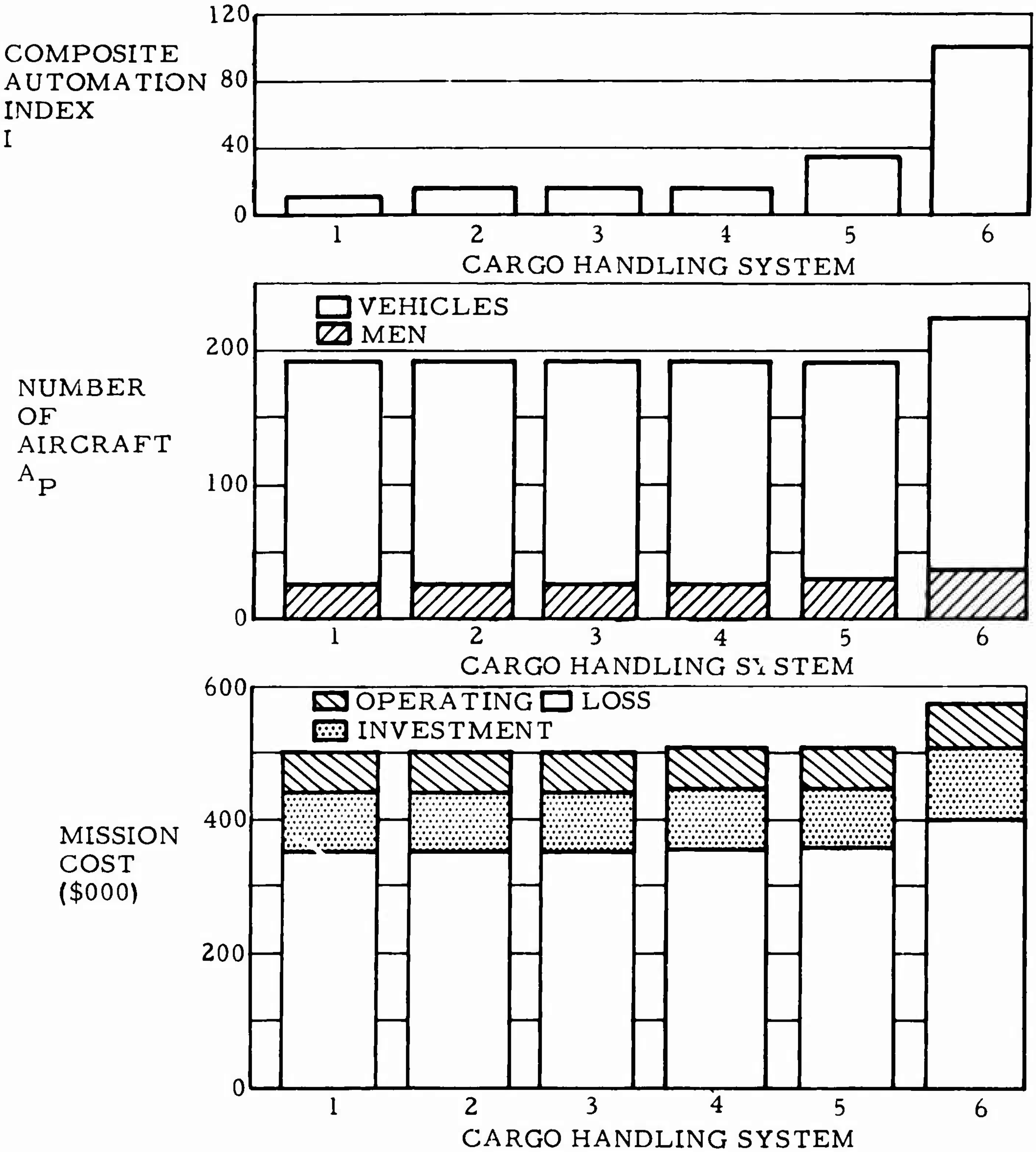


Figure 42. CV-2; Deployment Mission (Air Transportable Vehicles from the Airmobile Division); Comparison of Automation Index, Effectiveness, and Cost for Six Cargo Handling Systems

except 6, which, because more aircraft are required, is significantly higher. This leads to the conclusion that for the CV-2 the cargo handling system has little impact on the deployment mission, except when very highly automated systems are considered.

Table XXXIV shows the results of the analysis for the airdrop resupply mission. Only three of the systems evaluated were considered to be capable of airdrop of supplies. System 4 proved to be the most efficient airdrop system, having higher effectiveness and lower cost than either of the other two. The reason system 4 is better is because it is lighter than either 3 or 5 (12 percent lighter than 3 and 50 percent lighter than 5) and decreases cargo handling time considerably over system 3. Systems 4 and 5 have essentially equal cargo handling times, but the weight difference causes 5 to be less efficient. For the airdrop mission, operating cost is more than 90 percent of total mission cost. Investment and loss costs amount to less than 5 percent each. The operating cost is high because of the cargo preparation costs.

CV-7 BUFFALO

The results of the airland portion of the resupply missions are shown in Figures 43 and 44, and in Tables XXXV and XXXVI. Figure 43 shows the effectiveness and cost trends as the degree of cargo handling system automation increases. For the CV-7 aircraft (payload 10,000 pounds for 100-nautical-mile-radius mission), there is a range of automation index (0 to approximately 45) where effectiveness increases and cost decreases. In the 50 to 70 range, effectiveness is still roughly equal to that in the 30 to 50 range, but cost is steadily increasing. Effectiveness deteriorates starting at an automation index of about 70 to a point of effectiveness equal to the manual system at an index of about 85. From this point on additional automation causes a definite loss in effectiveness. The reason for these trends is that at low automation indexes, significant time savings relative to the aircraft cycle time are possible, and the weight penalty relative to the aircraft payload is small. With the highly automated systems, the weight penalty greatly overbalances the time savings. Of total mission cost, operating cost is about 55 percent, investment cost is 25 percent, and loss cost is 20 percent.

The area of interest on the trend plot (index range 30 to 70) is best discussed with reference to Figure 44. Figure 44 depicts the percent change in effectiveness and cost as the degree of cargo handling system automation increases relative to the manual system with an automation index of 18. For purposes of discussion, the dashed lines have been added midway between the Mission A and Mission B curves. The dashed lines are not a weighted average, but are shown to simplify discussion. Effectiveness gains from 3 percent to 10 percent and cost savings up to 5 percent are indicated.

TABLE XXXIV

CV-2; AIRDROP DAILY RESUPPLY; MANUAL WEIGHT AND BALANCE

	Mission A Air Assault Division			Mission B Road Infantry Elements		
Cargo Handling System	3	4	5	3	4	5
Composite Automation Index	60	91	102	60	91	102
% Increase in Automation Index*	0	51.7	70.0	0	51.7	70.0
Total Number Aircraft Required	1.54**	1.45	1.56	0.36***	0.34	0.37
% Change in Effectiveness*	0	+5.84	-1.30	0	+5.56	-2.78
Total Mission Cost ($000)	18.05	16.87	18.09	4.25	3.97	4.26
% Change in Cost*	0	-6.54	+0.22	0	-6.58	+0.24
Cost ($000) Breakdown						
Operating	16.59	15.44	16.55	3.90	3.63	3.90
Investment	0.72	0.69	0.74	0.17	0.16	0.18
Loss Cost	0.74	0.75	0.80	0.17	0.18	0.19

*All percentage changes are relative to the values obtained for the least automated cargo handling system.

**Airdrop of 17 tons.

***Airdrop of 4 tons.

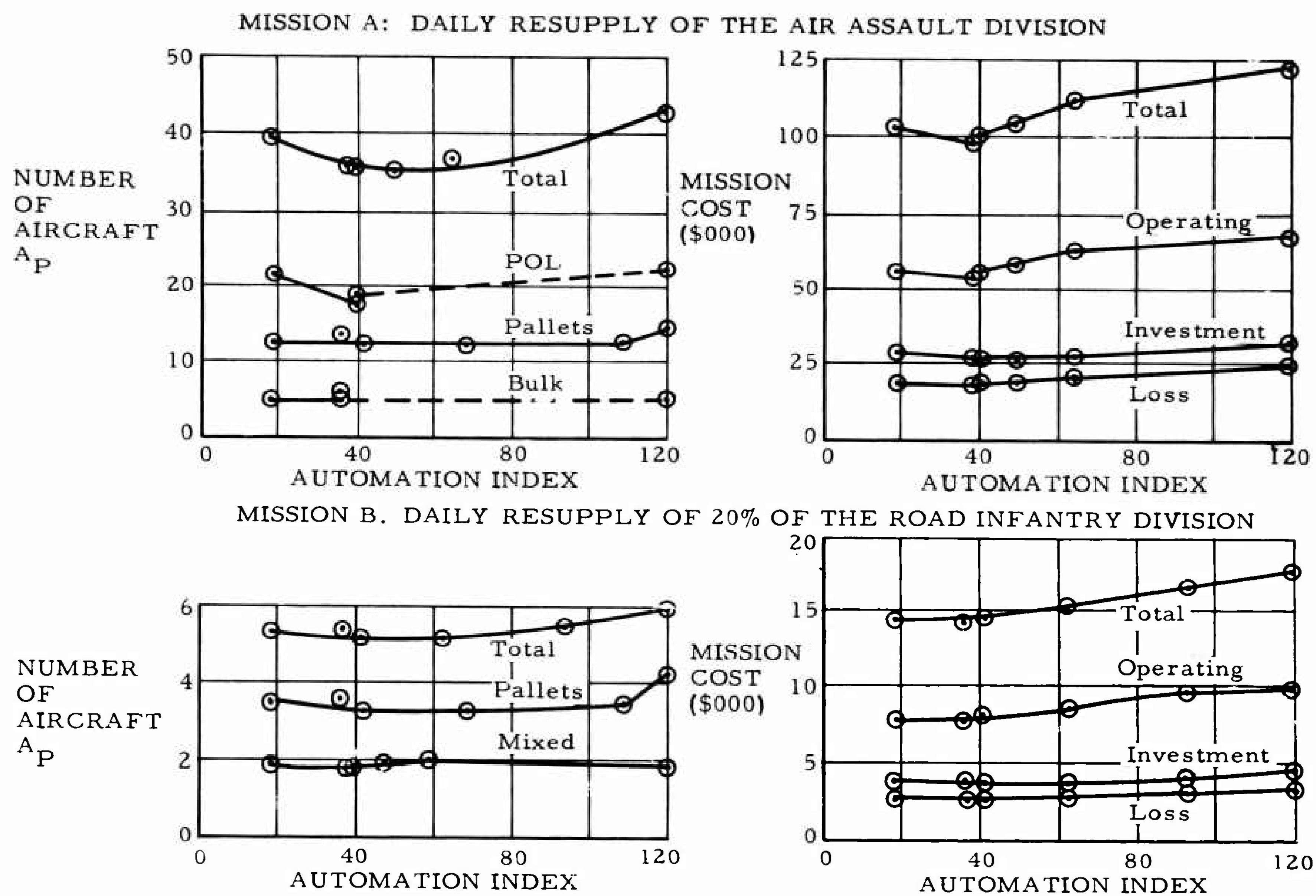


Figure 43. CV-7; Airland Resupply Missions; Effectiveness and Cost Trends as the Degree of Cargo Handling System Automation Increases

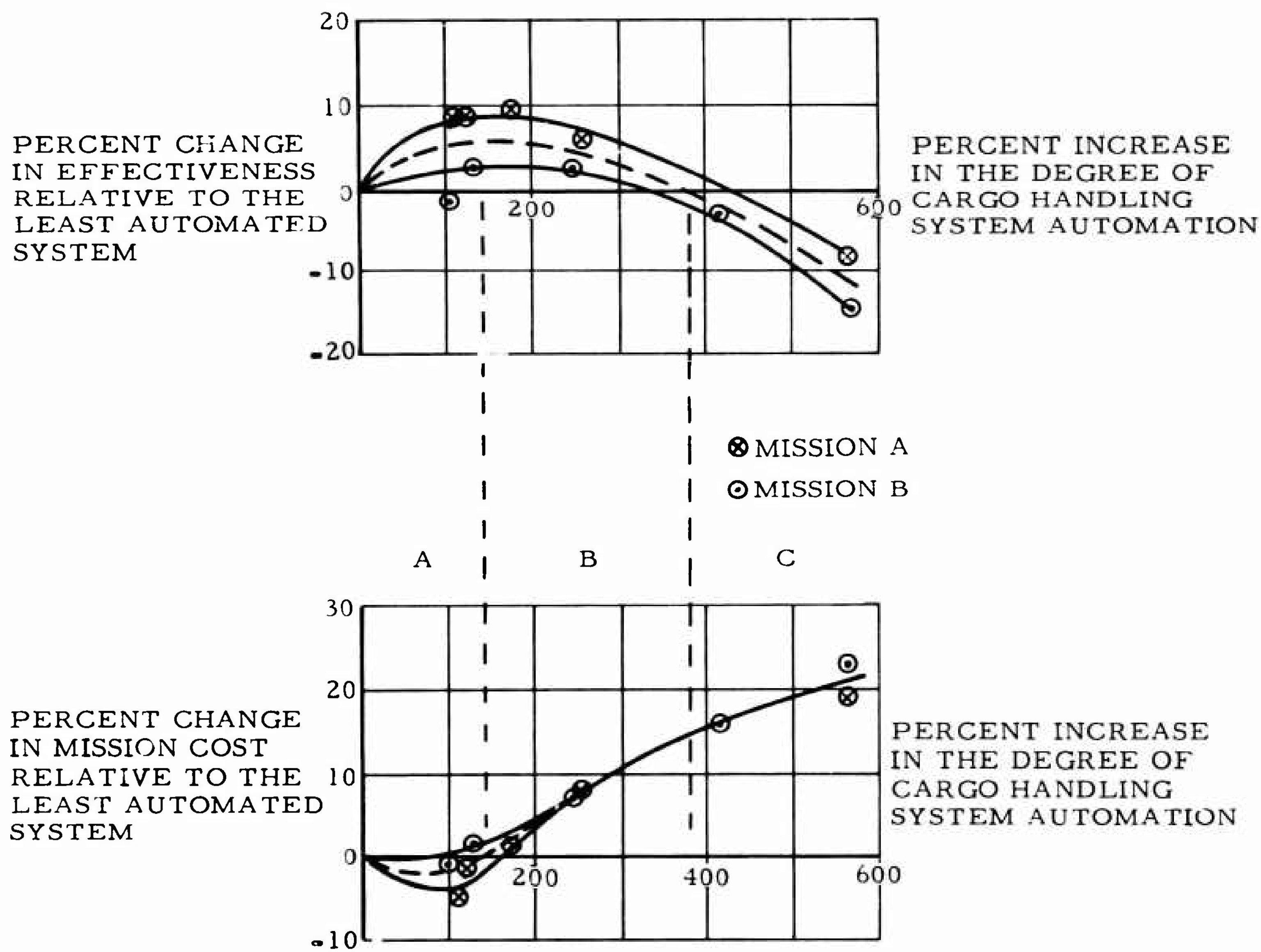


Figure 44. CV-7; Airland Resupply Missions; Percent Change in Effectiveness and Cost as the Degree of Cargo Handling System Automation Increases

TABLE XXXV

CV-7; AIRLAND DAILY RESUPPLY OF AIR ASSAULT DIVISION (MISSION A); MANUAL WEIGHT AND BALANCE

Cargo Handling System	1	2	3	4	5	6
Composite Automation Index	18.0	37.9	40.0	49.4	63.8	119.2
% Increase in Automation Index*	0	111.	122.	174.	254.	562.
Total Number Aircraft Required	39.13	35.84	35.89	35.27	36.81	42.27
% Change in Effectiveness*	0	+8.41	+8.29	+9.86	+5.93	-8.03
Total Mission Cost ($000)	102.66	97.36	101.23	103.72	111.18	121.99
% Change in Cost*	0	-5.16	-1.39	+1.04	+8.30	+19.00
Aircraft Required by Cargo Type**						
Pallets (268 tons)	12.43	13.17	11.86	11.80	12.37	14.52
Bulk (88 tons)	5.08	4.97	5.17	5.12	5.39	5.06
Men (5.4 tons)	0.22	0.22	0.24	0.22	0.26	0.30
POL (382 tons)	21.40	17.48	18.62	18.13	18.79	22.39
Cost ($000) Breakdown						
Operating	55.72	53.14	55.77	58.56	63.23	67.20
Investment	28.40	26.10	26.14	25.89	26.96	31.33
Loss Cost	18.54	18.12	19.32	19.28	20.99	23.47

*All percentage changes are relative to the values obtained for the least automated cargo handling system.

**Corresponding automation indexes given on page 73.

TABLE XXXVI

CV-7; AIRLAND DAILY RESUPPLY OF FORWARD ELEMENTS OF ROAD INFANTRY DIVISION (MISSION B); MANUAL WEIGHT AND BALANCE

Cargo Handling System	1	2	3	4	5	6
Composite Automation Index	18.0	36.3	41.1	61.7	92.9	120.0
% Increase in Automation Index*	0	102.	128.	243.	416.	567.
Total Number Aircraft Required	5.26	5.35	5.12	5.13	5.45	5.99
% Change in Effectiveness*	0	-1.71	+2.66	+2.47	-3.61	-13.88
Total Mission Cost ($000)	14.35	14.24	14.58	15.37	16.61	17.65
% Change in Cost*	0	-0.76	+1.58	+7.14	+15.77	+23.02
Aircraft Required by Cargo Type						
Pallets (75 tons)	3.43	3.56	3.31	3.28	3.43	4.19
Mixed (32.5 tons)	1.83	1.78	1.81	1.85	2.02	1.79
Cost ($000) Breakdown						
Operating	7.85	7.73	8.06	8.79	9.56	9.76
Investment	3.82	3.89	3.73	3.77	3.99	4.44
Loss Cost	2.68	2.62	2.79	2.82	3.07	3.45

*All percentage changes are relative to the values obtained for the least automated cargo handling system.

The letters A, B, and C in the following discussion refer to the areas shown in Figure 44. Area A indicates the portion of the curves where effectiveness is increasing and cost is lower or equal to that of the least automated system. The logical degree of automation for the CV-7 is in this area. Area B is that range of automation where effectiveness is better than the least automated system but cost is increasing. There may be justification for selecting a cargo handling system in this range of automation if the system has advantages that were not considered in the analysis or cannot be quantified. Area C is that range of automation where both effectiveness and cost are deteriorating with respect to the least automated system. Selection of a cargo handling system in this range of automation is not likely for the CV-7 aircraft.

Table XXXVII and Figure 45 show the results of the analysis for the deployment mission. As with the CV-2, the automation index is almost identical for four of the six systems. For all systems evaluated except system 2, the effectiveness deteriorates. A small increase is shown in system 2 because the system weight is low and cargo handling time (for vehicles) is unchanged. For this same reason, system 2 has lower cost. For the deployment mission in the CV-7 aircraft the factor most affecting effectiveness and mission cost is the cargo handling system weight. The cause of this is a load with a 3/4-ton truck and trailer which is payload limited in the CV-7. All other vehicles which will fit into the aircraft form volume limited payloads. The results of the analysis show that for the deployment missions a cargo handling system could be selected almost solely on weight. Operating cost, investment cost, and loss cost are about 55 percent, 25 percent, and 20 percent of total mission cost, respectively.

Table XXXVIII shows the results of the analysis for the airdrop resupply mission. For the CV-7 aircraft, the results of the airdrop mission are inconclusive. The reason for this is that the aircraft is limited to a 7500-pound single item drop weight. This figure was used in the analysis, and therefore the effect of the cargo handling system weight was not assessed.

For the airdrop mission, the operating cost is about 90 percent of the total mission cost. Investment cost is about 4 percent and loss cost is about 6 percent. The high operating cost is due to cargo preparation costs.

10-TON STOL

The results of the airland portion of the resupply mission are shown in Figures 46 and 47, and Tables XXXIX and XL show the results for the hypothetical 10-ton STOL. Figure 46 shows the effectiveness and cost trends as the degree of cargo handling system automation increases. For the 10-ton STOL (payload 20,000 pounds for 100-nautical-mile-radius mission) effectiveness increased and cost decreased over a wider range of automation index than with the CV-2 or CV-7. Changes in effectiveness, relative to the least automated system, range from 7 percent to 14 percent

TABLE XXXVII

CV-7; DEPLOYMENT OF AIR TRANSPORTABLE ELEMENTS OF AIRMOBILE DIVISION (MISSION A); MANUAL WEIGHT AND BALANCE

Cargo Handling System	1	2	3	4	5	6
Composite Automation Index	12.0	17.0	17.0	17.0	35.3	102.1
% Increase in Automation Index*	0	41.7	41.7	41.7	194.	751.
Total Number Aircraft Required	218.01	214.82	224.60	220.13	225.33	258.80
% Change in Effectiveness*	0	+1.46	-3.02	-0.97	-3.36	-18.71
Total Mission Cost ($000)	652.40	644.73	669.20	664.45	687.20	761.17
% Change in Cost*	0	-1.18	+2.58	+1.84	+5.33	+16.67
Aircraft Required by Cargo Type						
Men (709 tons)	28.24	27.58	29.60	28.98	31.10	39.11
Vehicles (3559 tons)	189.77	187.24	195.01	191.21	194.24	219.69
Cost ($000) Breakdown						
Operating	364.43	359.73	372.78	370.64	384.72	420.66
Investment	158.20	156.43	163.57	161.60	165.00	191.90
Loss Cost	129.77	128.63	132.85	132.21	137.49	148.62

*All percentage changes are relative to the values obtained for the least automated cargo handling system.

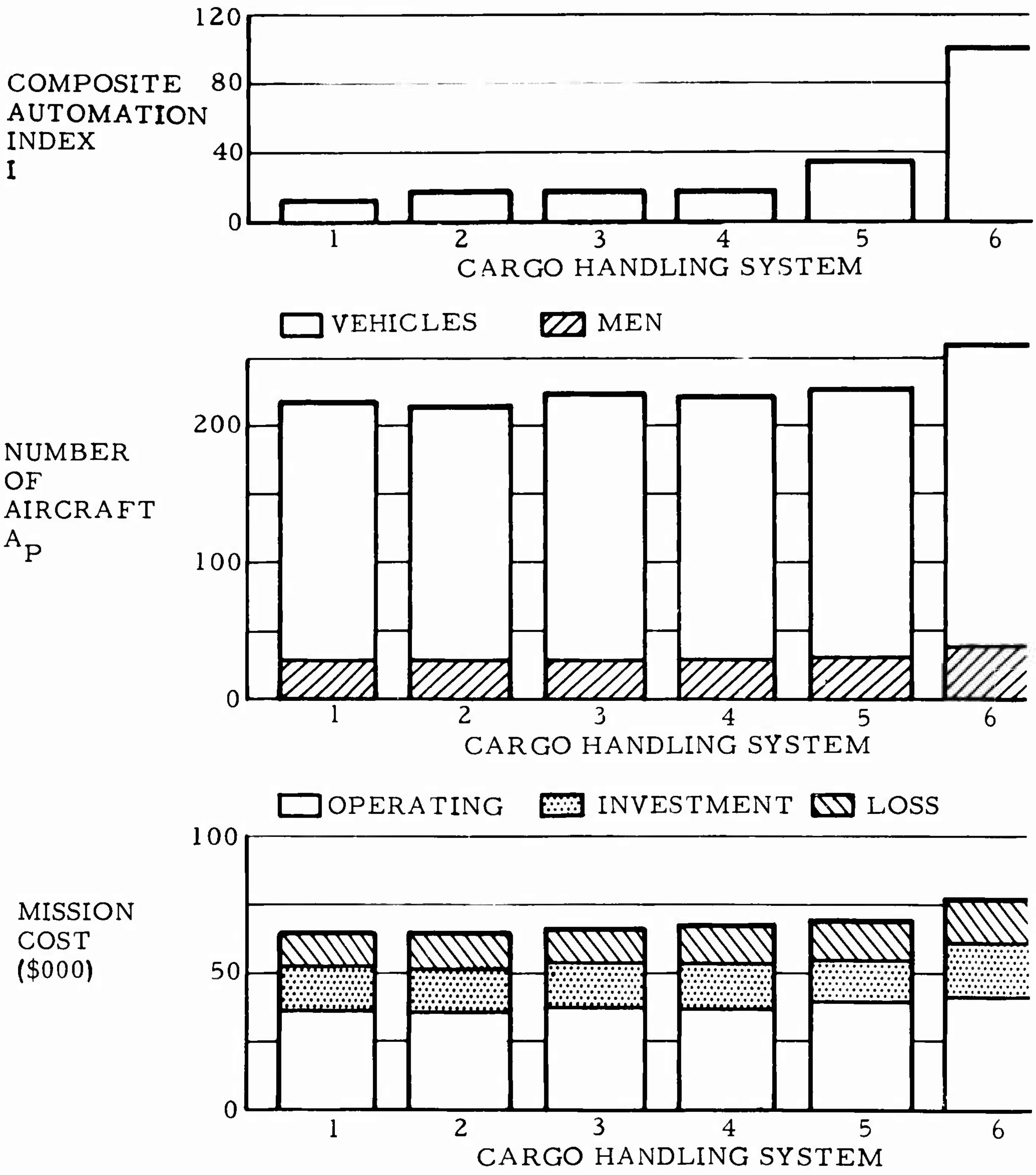


Figure 45. CV-7; Deployment Mission (Air Transportable Vehicles from the Airmobile Division); Comparison of Automation Index, Effectiveness, and Cost for Six Cargo Handling Systems

TABLE XXXVIII

CV-7; AIRDROP DAILY RESUPPLY; MANUAL WEIGHT AND BALANCE

	Mission A Air Assault Division			Mission B Road Infantry Elements		
Cargo Handling System	3	4	5	3	4	5
Composite Automation Index	60.0	91.0	102.0	60.0	91.0	102.0
Total Number Aircraft Required	1.00*	0.93	0.93	0.23**	0.22	0.22
Total Mission Cost ($000)	17.44	17.40	17.38	4.11	4.09	4.09
Cost ($000) Breakdown						
Operating	15.69	15.68	15.68	3.69	3.69	3.69
Investment	0.73	0.69	0.68	0.17	0.16	0.16
Loss Cost	1.03	1.03	10.3	0.24	0.24	0.24

*Airdrop of 17 tons

**Airdrop of 4 tons

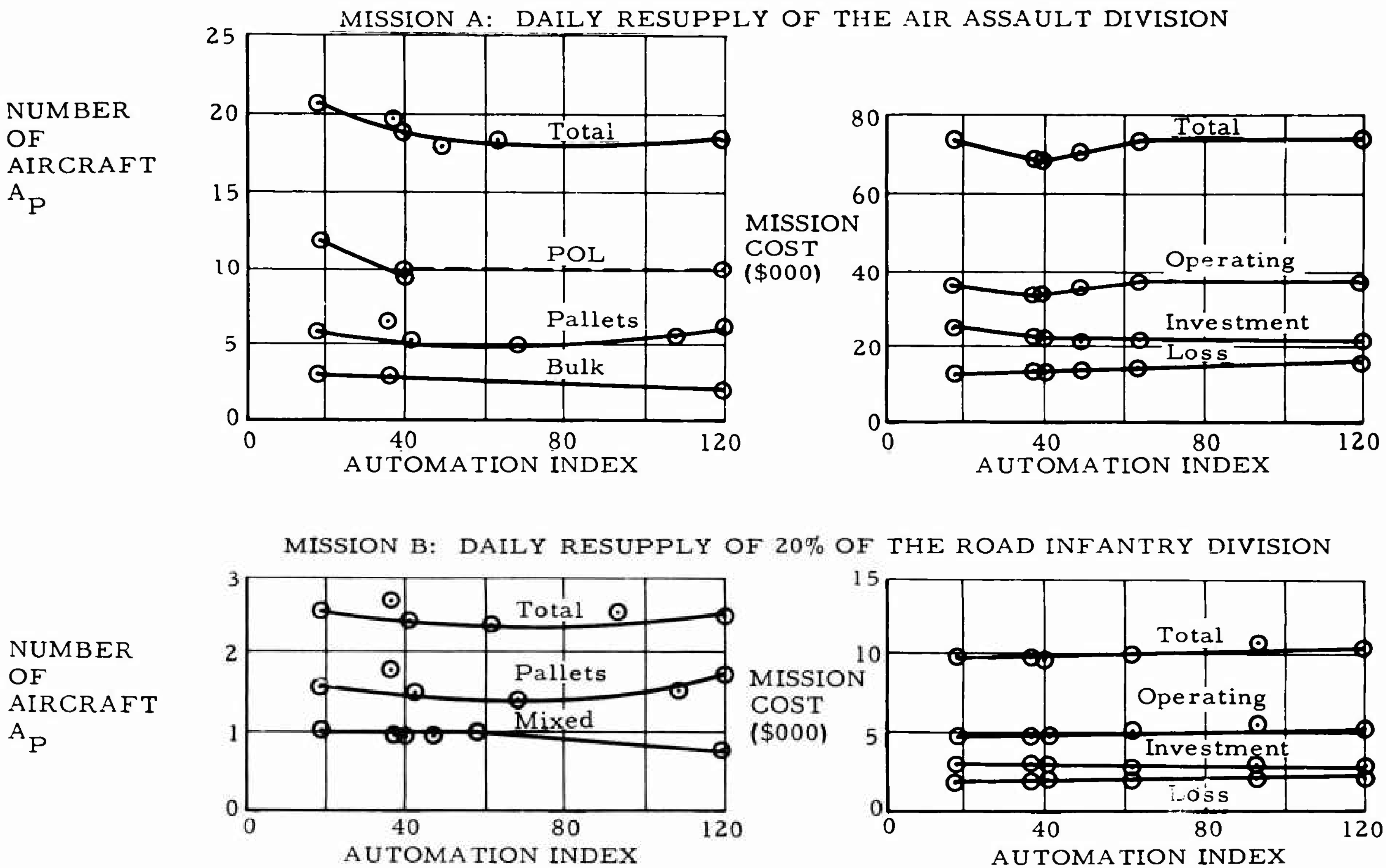


Figure 46. 10-Ton STOL; Airland Resupply Missions; Effectiveness and Cost Trends as the Degree of Cargo Handling System Automation Increases

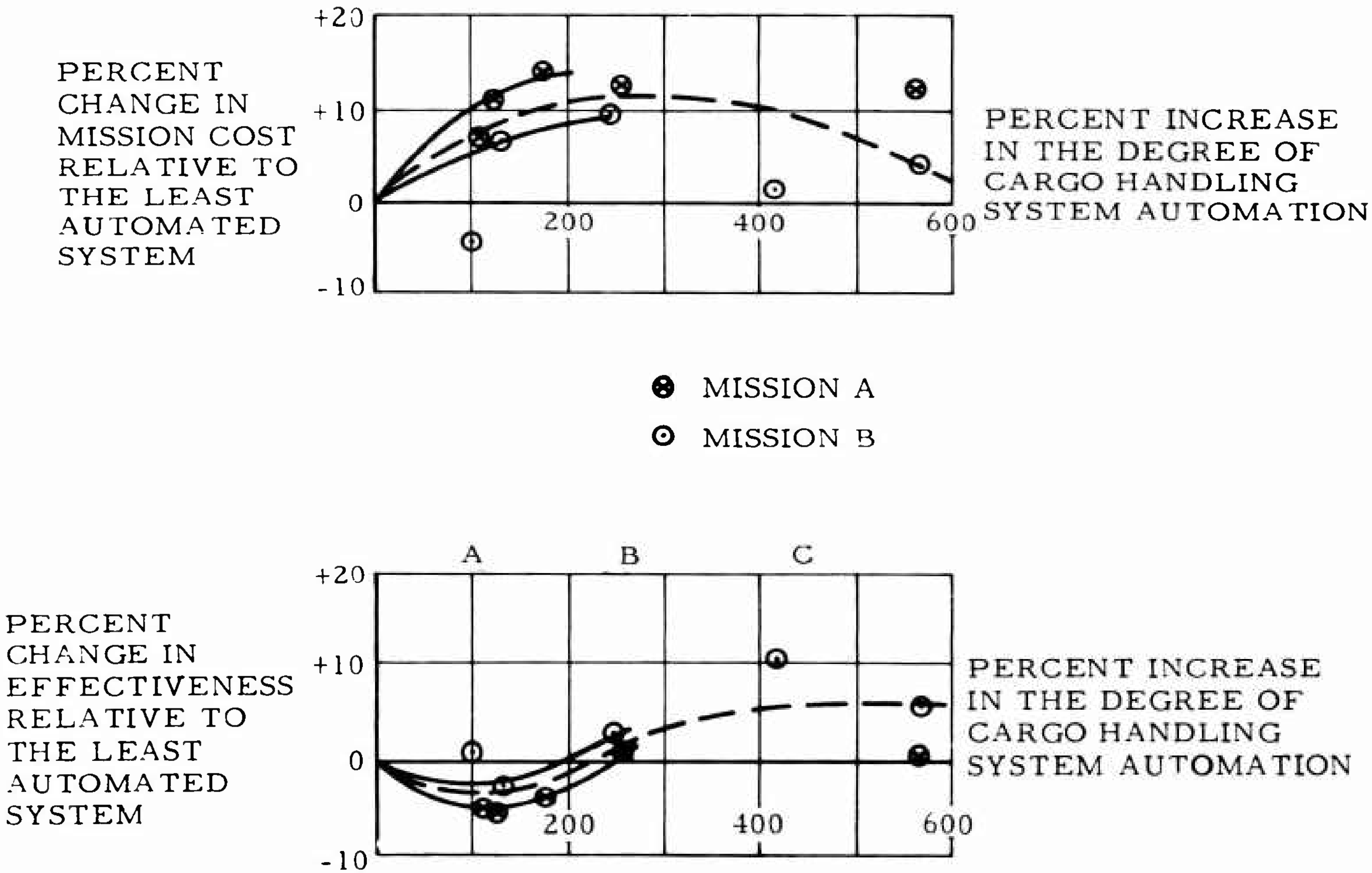


Figure 47. 10-Ton STOL; Airland Resupply Missions; Percent Change in Effectiveness and Cost as the Degree of Cargo Handling System Automation Increases

TABLE XXXIX

10-TON STOL; AIRLAND DAILY RESUPPLY OF AIR ASSAULT DIVISION (MISSION A); MANUAL WEIGHT AND BALANCE

Cargo Handling System	1	2	3	4	5	6
Composite Automation Index	18.0	37.9	40.0	49.4	63.8	119.2
% Increase in Automation Index*	0	111.	122.	174.	254.	562.
Total Number Aircraft Required	20.92	19.38	18.51	17.93	18.28	18.29
% Change in Effectiveness*	0	+7.37	+11.53	+14.32	+12.63	+12.59
Total Mission Cost ($000)	73.03	69.12	68.93	70.27	73.59	73.41
% Change in Cost*	0	-5.35	-5.61	-3.78	+0.77	+0.52
Aircraft Required by Cargo Type**						
Pallets (268 tons)	5.69	6.61	5.35	3.98	5.46	6.13
Bulk (88 tons)	2.97	2.96	2.99	2.99	3.12	2.08
Men (5.4 tons)	0.17	0.17	0.17	0.17	0.17	0.18
POL (382 tons)	12.09	9.64	10.00	9.79	9.54	9.90
Cost ($000) Breakdown						
Operating	35.29	33.29	33.63	35.57	37.53	36.35
Investment	24.40	22.66	21.65	21.06	21.45	21.67
Loss Cost	13.35	13.16	13.66	13.64	14.61	15.38

*All percentage changes are relative to the values obtained for the least automated cargo handling system.

**Corresponding automation given on page 73.

TABLE XL

10-TON STOL; AIRLAND DAILY RESUPPLY OF FORWARD ELEMENTS OF ROAD INFANTRY DIVISION (MISSION B); MANUAL WEIGHT AND BALANCE

Cargo Handling System	1	2	3	4	5	6
Composite Automation Index	18.0	36.3	41.1	61.7	92.9	120.0
% Increase in Automation Index*	0	102.	128.	243.	416.	567.
Total Number Aircraft Required	2.57	2.68	2.39	2.33	2.53	2.46
% Change in Effectiveness*	0	-4.28	+7.01	+9.35	+1.57	+4.28
Total Mission Cost ($000)	9.68	9.75	9.45	9.95	10.73	10.25
% Change in Cost*	0	+0.72	-2.38	+2.95	+10.85	+5.90
Aircraft Required by Cargo Type						
Pallets (75 tons)	1.56	1.75	1.49	1.38	1.52	1.71
Mixed (32.5 tons)	1.01	0.93	0.91	0.94	1.01	0.74
Cost ($000) Breakdown						
Operating	4.75	4.72	4.69	5.23	5.63	5.12
Investment	3.02	3.14	2.80	2.74	2.97	2.91
Loss Cost	1.92	1.89	1.96	1.98	2.13	2.22

*All percentage changes are relative to the values obtained for the least automated cargo handling system.

improvement over a wide range of automation index (approximately 35 to 90). Cost savings of more than 5 percent are possible in an automation index range of about 40.

Of total mission cost, operating cost is about 50 percent, investment cost 30 percent, and loss cost 20 percent.

In Mission B, the effectiveness point for system 2 does not fall on the curve. The reason for this is that the Mission B cargo is predominantly pallets, and with system 2, only one winch is provided in the 10-ton STOL to load these pallets. With the other cargo handling systems, the width of the 10-ton STOL allows using a larger loading crew to reduce cargo handling time. With system 2, loading time is greatly increased, largely due to the rigging time required with the single winch and large payload.

While this same constraint affected the other aircraft, it is accented by the size and speed of the 10-ton STOL. The aircraft payload is high and the cargo handling system weight has a less detrimental effect; that is, less percent payload degradation than in the CV-7 or CV-2. More important, the aircraft speed is higher (400 knots for the 10-ton STOL versus 225 knots for the CV-7 and 153 knots for the CV-2), and therefore total cycle time is reduced. The cycle time, excluding cargo handling time, is 138 minutes for the CV-2, 108 minutes for the CV-7, and only 83.5 minutes for the 10-ton STOL. An increase or decrease in cargo handling time is therefore more significant in the 10-ton STOL than in the CV-7 or CV-2, since it has a greater impact on the total cycle time and thereby on delivery system productivity.

Figure 47 shows the percentage changes in effectiveness and cost as the degree of cargo handling system automation increases. Discussion of these curves is best carried on in relation to the CV-7 curves (Figure 44).

The 10-ton STOL curves are similar to those for the CV-7, with three differences due to the higher speed, larger payload, and wider floor of the former. These three differences are:

1. Cost savings and effectiveness gains accrue over a wider range of automation.

2. The percentage of decreases in cost and increases in effectiveness are larger.

3. Costs do not increase and effectiveness does not decrease as rapidly at the higher degrees of cargo handling system automation.

If the points for system 6 were removed from Figure 47 (conveyor system in the 10-ton STOL), the curves would be very similar to those for the CV-7 up

to a 400-percent increase in automation index (relative to a base case, index of 18 in both cases).

The points for system 6 depart radically from the above trend. System 6 in the 10-ton STOL has a definite increase in effectiveness, relative to system 1. System 6 in the CV-7 results in a decrease in effectiveness relative to system 1. The cost penalty of system 6 is less for the 10-ton STOL than for the CV-7. This is due to the fact that the time savings with system 6 in the 10-ton STOL are magnified by its size and speed, and therefore overbalance the detrimental effect of the system weight. The CV-7, being slower and having a smaller payload, is affected in the opposite way. The difference in time savings and payload degradation for system 6 relative to system 1 for both the CV-7 and 10-ton STOL is shown in Table XLI. Because system 6 causes greater payload degradation in the CV-7, the number of single aircraft cycles increases much more with the CV-7 than with the 10-ton STOL. At the same time, the relative decrease in cargo handling time is more per single aircraft load with the 10-ton STOL than with the CV-7. These advantages for the 10-ton STOL result in the effectiveness gains evidenced with system 6 in this aircraft.

TABLE XLI

PERCENT DECREASE IN CARGO HANDLING TIME AND PAYLOAD FOR SYSTEM 6 RELATIVE TO SYSTEM 1 IN THE CV-7 AND THE 10-TON STOL

	Percent Decrease Cargo Handling Time		Percent Decrease Payload	
Cargo Type	CV-7	10-Ton STOL	CV-7	10-Ton STOL
Large Bulk	73.6	81.7	19.3	12.0
Small Bulk	79.7	88.8	19.3	12.0
Mixed	88.3	87.3	19.3	12.0
POL	72.0	75.0	19.3	12.0

Table XLII and Figure 48 show the results of the analysis for the deployment mission. The automation index for vehicles changes very little for four of the six systems evaluated. For all systems investigated, the relative effectiveness of the systems is almost in direct relationship to the system weight. This is because the 10-ton STOL was sized to carry enough vehicles to utilize all of the available payload, and vehicle cargo handling time changes very little as automation increases. Of total mission cost,

TABLE XLII

10-TON STOL; DEPLOYMENT OF AIR TRANSPORTABLE ELEMENTS OF AIRMOBILE DIVISION (MISSION A); MANUAL WEIGHT AND BALANCE

Cargo Handling System	1	2	3	4	5	6
Composite Automation Index	12.0	16.9	16.9	16.9	34.9	100.5
% Increase in Automation Index*	0	41.	41.	41.	191.	738.
Total Number Aircraft Required	147.12	144.25	153.74	147.30	158.17	166.85
% Change in Effectiveness	0	+1.95	-4.50	-0.12	-7.51	-13.41
Total Mission Cost ($000)	579.47	570.11	599.40	584.02	627.69	666.43
% Change in Cost	0	-1.61	+3.44	+0.79	+8.32	+15.00
Aircraft Required by Cargo Type						
Men (tons)	22.25	21.97	22.76	22.25	23.97	28.06
Vehicles (tons)	124.87	122.28	130.98	125.05	134.19	138.79
Cost ($000) Breakdown						
Operating	287.56	282.73	296.42	289.83	312.22	329.73
Investment	171.61	168.65	179.75	173.05	185.61	197.71
Loss Cost	120.30	118.73	123.24	121.15	129.87	138.99

*All percentage changes are relative to the values obtained for the least automated cargo handling system.

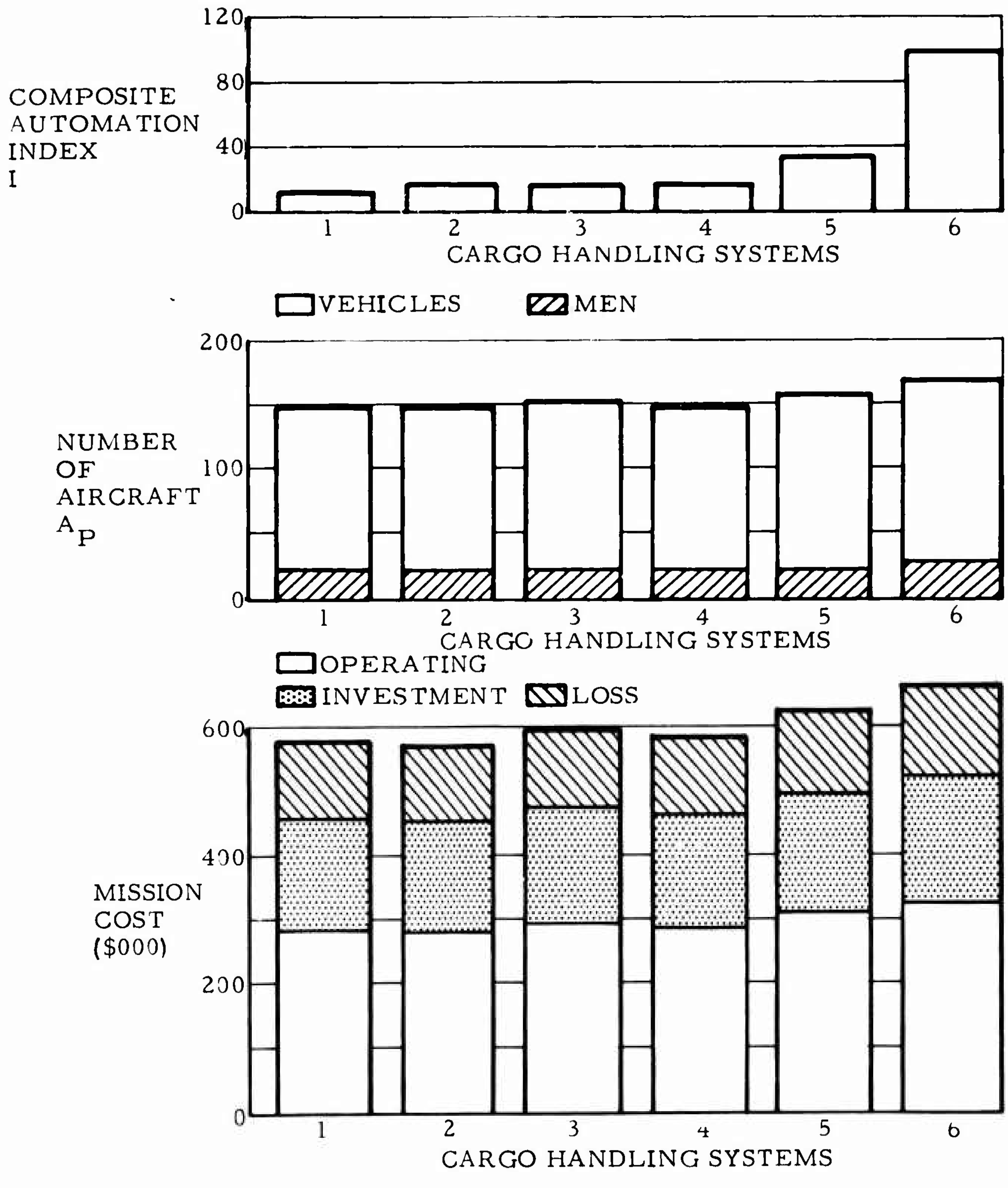


Figure 48. 10-Ton STOL; Deployment Mission (Air Transportable Vehicles from the Airmobile Division); Comparison of Automation Index, Effectiveness, and Cost for Six Cargo Handling Systems

operating cost is about 50 percent, investment cost 30 percent, and loss cost 20 percent.

Table XLIII shows the results of the analysis for the airdrop resupply mission. Of the three systems evaluated for airdrop, system 4 resulted in the highest effectiveness and lowest cost. The operating cost is over 92 percent of the total mission cost. Investment cost is less than 3 percent and loss cost is less than 5 percent. The operating cost is high because of the cargo preparation cost.

CH-47 CHINOOK

The results of the airland portion of the resupply missions are shown in Figures 49 and 50 and in Tables XLIV and XLV. Figure 49 shows the effectiveness and cost trends as the degree of cargo handling system automation increases. For the CH-47 helicopter (14,000-pound payload for the 20-nautical-mile-radius mission), the effectiveness is improved approximately the same amount over the range of automation index from 40 to 90. There is a slight cost reduction (2 percent to 3 percent) in relation to the least automated system, at an automation index of about 35, after which cost increases up to an automation index of about 90, remaining constant at about 10-percent cost penalty for higher degrees of automation.

In the case of the helicopter, the mission is delivery to a forward area proper, and the total cargo composition changes significantly. The bulk of the cargo in both Missions A and B is pallets. Inspection of Figure 49 shows the influence of this, as the shape of the total cargo curve and the palletized cargo curve are very similar. For both Missions A and B, system 2 does not fall on the curve. This is because of the predominance of palletized cargo and the fact that the winch must be rerigged for loading each pallet.

In addition to the predominance of pallets, two items affect the results. First, the mission radius is short, resulting in cargo handling time being a large portion of the total cycle time. Second, the aircraft payload is high for the short radius mission, so the weight of the cargo handling system amounts to a smaller percentage of the payload than with either the CV-2 or CV-7.

Figure 50 shows the percentage of change in cost and effectiveness as the degree of cargo handling system automation increases. The effectiveness increases rapidly to about a 12.5-percent improvement. This magnitude of improvement is possible over a range of automation index from 40 to 90. Cost, on the other hand, decreases for the range of automation index around 35 and then increases to a maximum about 10 percent higher than the least automated system. Of the total mission cost, operating cost is about 35 percent, investment cost 20 percent, and loss cost 45 percent.

TABLE XLIII

10-TON STOL; AIRDROP DAILY RESUPPLY; MANUAL WEIGHT AND BALANCE

	Mission A Air Assault Division			Mission B Road Infantry Elements		
Cargo Handling System	3	4	5	3	4	5
Composite Automation Index	60.0	91.0	102.0	60.0	91.0	102.0
Total Number Aircraft Required	0.29*	0.25	0.26	0.07**	0.06	0.06
Total Mission Cost ($000)	13.79	13.07	14.13	3.24	3.07	3.32
Cost ($000) Breakdown						
Operating	12.87	12.21	13.21	3.03	2.87	3.11
Investment	0.34	0.29	0.31	0.08	0.07	0.07
Loss Cost	0.58	0.57	0.61	0.14	0.14	0.14

*Airdrop of 17 tons.

**Airdrop of 4 tons.

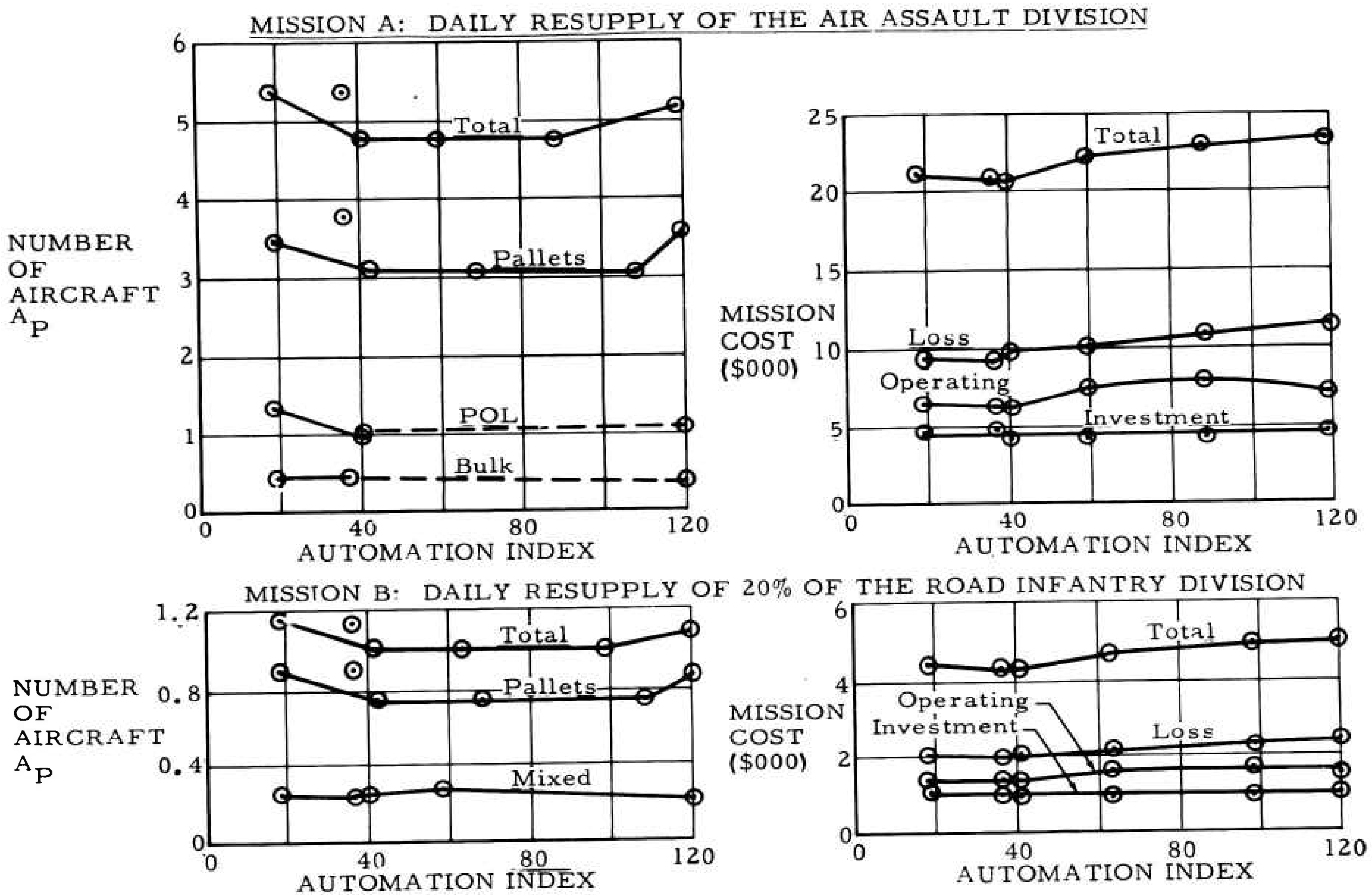


Figure 49. CH-47; Airland Resupply Missions; Effectiveness and Cost Trends as the Degree of Cargo Handling System Automation Increases

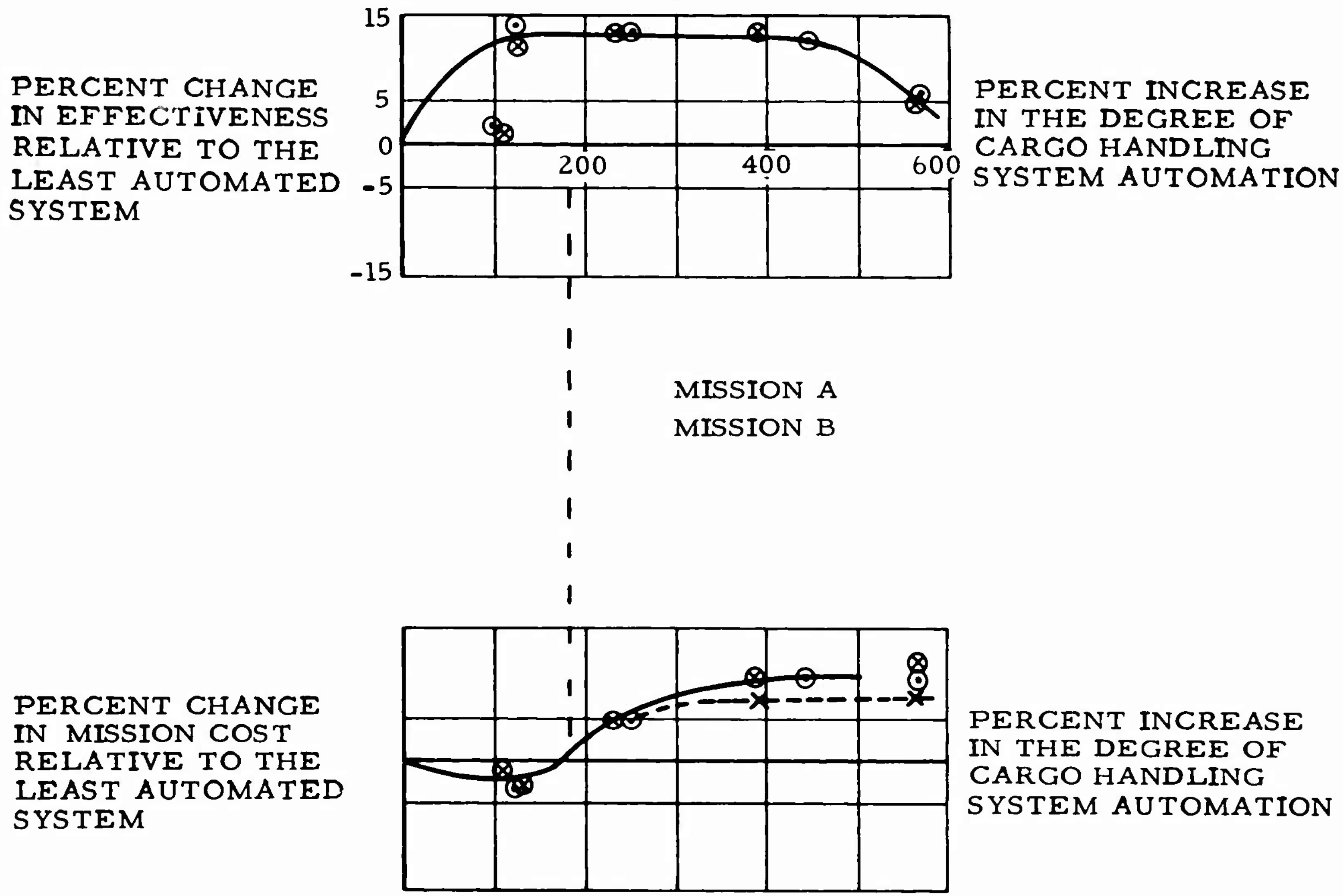


Figure 50. CH-47; Airland Resupply Missions; Percent Change in Effectiveness and Cost as the Degree of Cargo Handling System Automation Increases

TABLE XLIV

CH-47; AIRLAND DAILY RESUPPLY OF AIR ASSAULT DIVISION (MISSION A); MANUAL WEIGHT AND BALANCE

Cargo Handling System	1	2	3	4	5	6
Composite Automation Index	18.0	36.4	40.6	59.1	87.6	117.9
% Increase in Automation Index*	0	102.0	125.5	228.	387.	564.
Total Number Aircraft Required	5.41	5.39	4.78	4.74	4.74	5.18
% Change in Effectiveness*	0	+0.37	+11.65	+12.38	+12.38	+4.25
Total Mission Cost ($000)	21.09	20.84	20.55	22.09	23.05	23.26
% Change in Cost*	0	-1.23	-2.65	+4.72	+9.29	+10.27
Aircraft Required by Cargo Type**						
Pallets (111 tons)	3.44	3.78	3.10	3.09	3.08	3.55
Bulk (10 tons)	0.44	0.44	0.45	0.44	0.46	0.36
Men (3 tons)	0.16	0.16	0.16	0.16	0.16	0.18
POL (32 tons)	1.36	1.01	1.06	1.04	1.03	1.10
Cost ($000) Breakdown						
Operating	6.69	6.59	6.40	7.65	8.00	7.21
Investment	4.82	4.83	4.27	4.27	4.26	4.71
Loss Cost	9.58	9.42	9.87	10.18	10.80	11.34

*All percentage changes are relative to the values obtained for the least automated cargo handling system.

**Corresponding automation indexes given on page 73.

TABLE XLV

C-47; AIRLAND DAILY RESUPPLY OF FORWARD ELEMENTS OF ROAD INFANTRY DIVISION (MISSION B); MANUAL WEIGHT AND BALANCE

Cargo Handling System	1	2	3	4	5	6
Composite Automation Index	18.0	36.0	40.8	62.6	98.3	120.0
% Increase in Automation Index*	0	100.	127.	248.	446.	567.
Total Number Aircraft Required	1.15	1.13	0.99	1.00	1.01	1.08
% Change in Effectiveness*	0	+1.74	+13.91	+13.04	+12.17	+6.09
Total Mission Cost ($000)	4.45	4.36	4.30	4.66	4.88	4.88
% Change in Cost*	0	-2.02	-3.37	+4.74	+9.68	+9.68
Aircraft Required by Cargo Type						
Pallets (27 tons)	0.90	0.89	0.75	0.75	0.74	0.86
Mixed (6.5 tons)	0.25	0.24	0.24	0.25	0.27	0.21
Cost (4000) Breakdown						
Operating	1.41	1.38	1.34	1.62	1.70	1.51
Investment	1.03	1.01	0.89	0.90	0.91	0.98
Loss Cost	2.01	1.97	2.07	2.14	2.28	2.39

*All percentage changes are relative to the values obtained for the least automated cargo handling system.

Loss cost is much more significant for the CH-47 because the aircraft flies many short range missions, all in vulnerable areas.

One additional feature is included in Figure 50. In the cost plot, the dotted line which shows a maximum cost increase of about 7.5 percent is an estimate of the possible savings due to decreased vulnerability. The basic analysis was performed with the losses due to enemy fire, while stationary on the ground, constant per exposure. That is, the probability of an aircraft being lost when landing and discharging cargo in a forward area was constant regardless of the time spent static in the vulnerable area. The dotted portion of the curve was constructed based on the following assumptions:

1. Of the time in the forward area, that time used in approach, landing, takeoff, and climb was constant regardless of the cargo handling time, and therefore the losses were also constant. Fifty percent of the losses to enemy fire were assumed to be while airborne.

2. The remaining time in the forward area was when the aircraft was static on the ground. Fifty percent of the losses to enemy fire were assumed to occur while on the ground. Using the least automated cargo handling system time as a base, these losses were reduced in direct proportion to the cargo handling time reduction. For example, if a system required one-half of the cargo handling time that the base system required, losses while static on the ground were reduced 50 percent.

Table XLVI and Figure 51 show the results of the analysis for the deployment mission. The automation index is relatively constant for systems 1 through 4 and increases for systems 5 and 6. Effectiveness is also relatively constant for systems 1 through 4. Effectiveness increases for system 5. This is because the CH-47 is volume limited when transporting vehicles with cargo handling system 5. The system weight is not detrimental, but system 5 aids in restraining vehicles, thereby reducing the cargo handling time for vehicles. The total mission cost for system 5 is likewise reduced. Cargo handling system 6 has decreased effectiveness (relative to system 1) because the payload of the aircraft is reduced to a point where the vehicle loads are payload limited, thus increasing the total number of aircraft required.

Of total mission cost, for the deployment mission, operating cost was 30 percent, investment cost 20 percent, and loss cost 50 percent.

TABLE XLVI

CH-47; DEPLOYMENT OF AIR TRANSPORTABLE ELEMENTS OF AIRMOBILE DIVISION (MISSION A); MANUAL WEIGHT AND BALANCE

Cargo Handling System	1	2	3	4	5	6
Composite Automation Index	12.0	17.0	17.0	17.0	35.3	102.1
% Increase in Automation Index	0	42.	42.	42.	194.	751.
Total Number Aircraft Required	184.23	184.23	184.23	184.23	174.39	196.10
% Change in Effectiveness*	0	0	0	0	+5.30	-6.44
Total Mission Cost ($000)	855.94	857.44	857.52	864.17	847.47	889.23
% Change in Cost*	0	+0.18	+0.19	+0.96	-0.99	+3.89
Aircraft Required by Cargo Type						
Men (709 tons)	28.82	28.82	28.82	28.82	28.82	32.11
Vehicles (3559 tons)	155.41	155.41	155.41	155.41	145.57	163.99
Cost ($000) Breakdown						
Operating	262.94	262.96	262.97	265.62	259.13	275.10
Investment	164.36	164.82	164.84	165.94	156.71	178.04
Loss Cost	428.64	429.66	429.71	432.60	431.63	436.10

*All percentage changes are relative to the values obtained for the least automated cargo handling system.

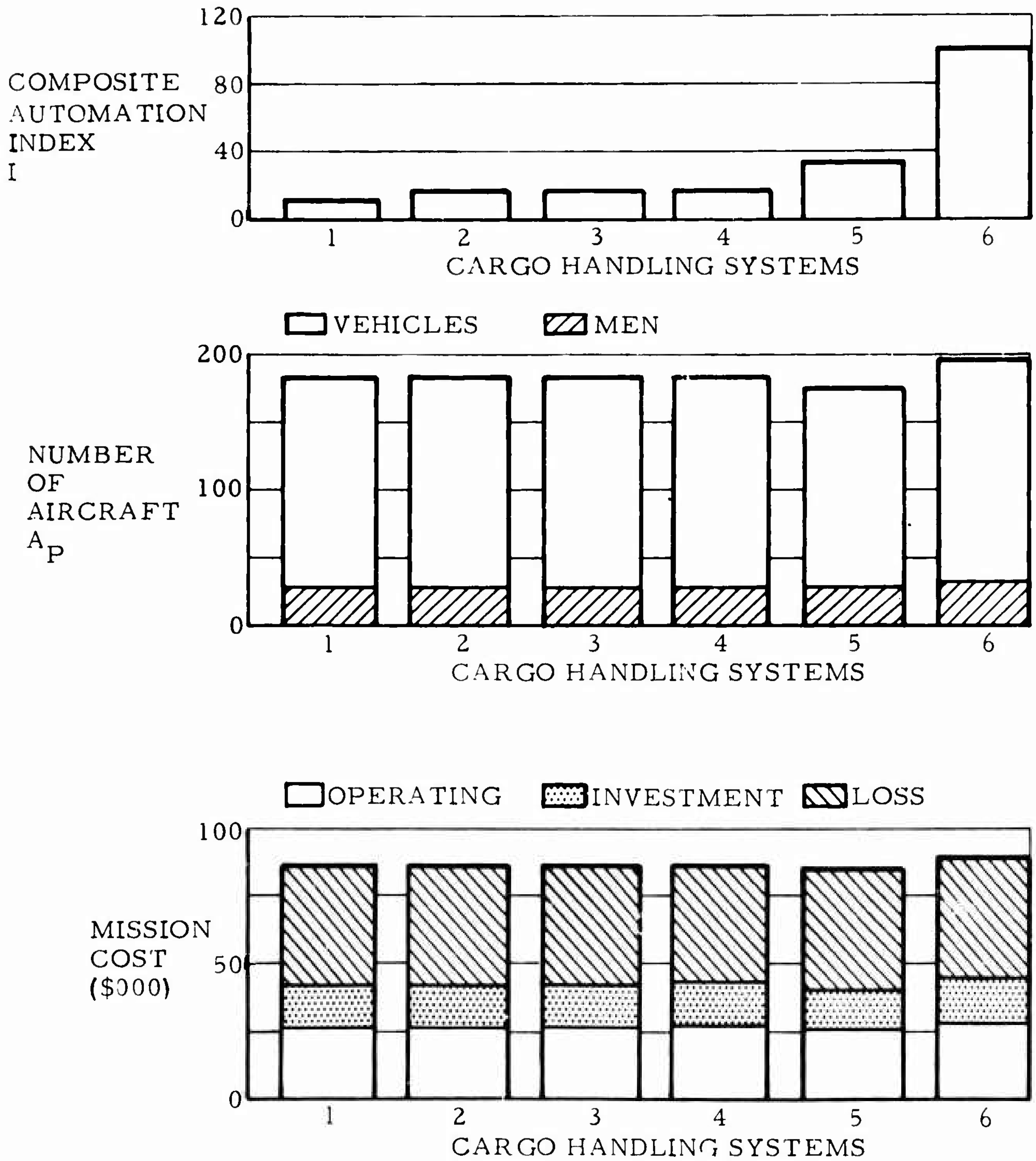


Figure 51. CH-47; Deployment Mission (Air Transportable Vehicles from the Airmobile Division); Comparison of Automation Index, Effectiveness, and Cost for Six Cargo Handling Systems

WEIGHT AND BALANCE

Figure 52 shows the results of the analysis for automated versus manual weight and balance for the CV-7 aircraft. This curve is typical of the results for all aircraft investigated. In all cases, automated weight and balance resulted in savings. This is because the automated weight and balance system is lightweight (about 30 pounds) and results in considerable time savings. In addition to offering savings, the automated weight and balance system also contributes to safety in forward area operations in that it becomes a very simple matter to check the aircraft center-of-gravity location and gross weight prior to takeoff.

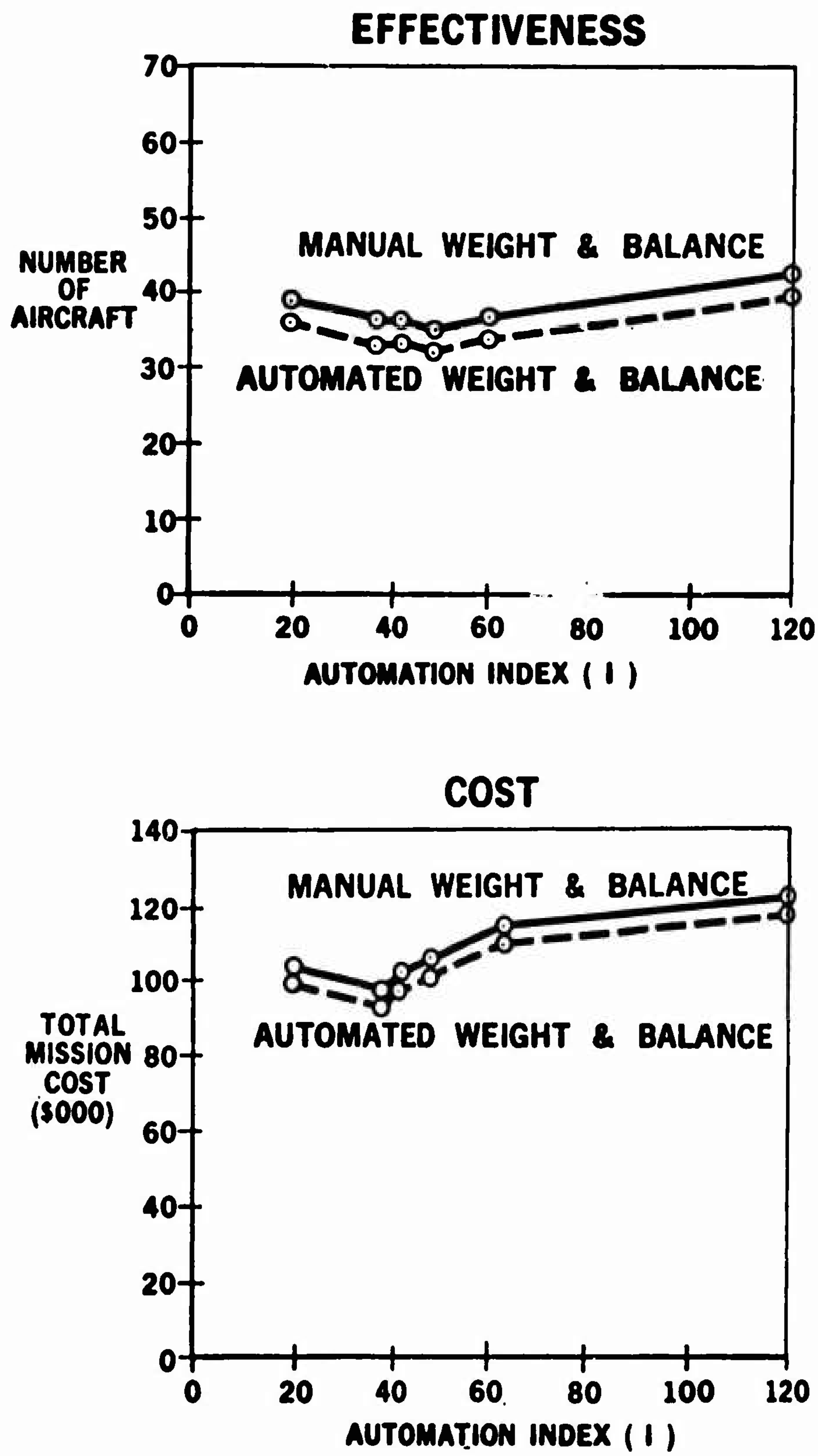


Figure 52. Effect of Automated Weight and Balance on Effectiveness and Cost; CV-7 Mission A Resupply

QUALITATIVE CONSIDERATIONS

In addition to factors which have been evaluated in a quantitative manner, there are several factors which do not lend themselves to quantitative analysis and must be subject to a qualitative analysis:

1. The compatibility of a system with the airdrop of supplies depends on the importance of airdrop delivery to the evaluator. Systems 1 and 2 do not allow for airdrop of cargo by parachute extraction. Small items could be airdropped by manually pushing them out of the aircraft, but this is both a dangerous and inefficient procedure. Systems 3, 4, and 5 have the capability of airdropping loads up to the limits of the aircraft. System 6 is capable of ejecting supplies, using the conveyor belt; however, heavy cargo weights would probably have adverse effect on the stability and control of the aircraft. System 6 was not considered suitable for airdrop delivery.

2. One factor must be considered in the systems with airdrop capability. This is the release of restraint. In system 3, cargo is restrained on the roller conveyors with tiedown straps or chains. This restraint must be released prior to the actual drop. All restraint except shear straps is removed 6 minutes prior to arrival at the drop zone. During this time, the load is not restrained in the aft direction for flight loads. Forward movement is restricted by a buffer board installed on the skate wheel conveyor sections. This creates a potentially hazardous condition. Systems 4 and 5 are equipped with a mechanical latch which is released by the extraction parachute pull and which will withstand normal flight loads.

   The rigging for systems 4 and 5 is much simpler, and loading time and manpower are both reduced.

3. Two items involving personnel must be considered: number of personnel and training requirements. There is an interplay between these two items which is difficult to quantify. As systems become more automated, fewer personnel are required to operate the system, but they are more highly trained. System 1 requires little training for the crew, but, in order to achieve minimum loading time, the crew must be large. System 2 also requires a minimum of training, but, because a winch is available, the crew size is reduced. System 3 can utilize some personnel with minimum training, but, because of installation of the system and airdrop, procedures will require considerable training for most personnel. Systems 4, 5, and 6 require small trained crews for efficient operation.

4. Systems 1 and 2 can be maintained with regularly trained aircraft mechanics, but systems 3, 4, 5, and 6 will require more training for maintenance personnel.

5. The compatibility of the cargo handling system with other links in the total delivery system (manufacturer to user) must be considered. For example, the adoption of a standard platform or pallet for use throughout the complete system could affect the cargo handling system selection.

6. The actual time to load an aircraft has been used as a major criterion for the effectiveness of the various cargo handling systems. This time is significantly decreased when loading palletized cargo for systems 4 and 5. One item was not accounted for with these two systems. The elapsed time and manpower required to prepare cargo prior to loading was included in mission cost but did not affect the aircraft cycle time. Both systems require that cargo be repalletized on larger pallets. The situation could arise where an inadequate number of pallets were available. Then the cargo preparation time (as well as depalletizing at the off-load site so that the pallets could return with the aircraft) could, in fact, become part of the aircraft cycle time.

7. Systems which require preparation of cargo prior to loading (4 and 5) are characterized by an increase in the overall response time to emergency requirements. Response time to emergency requests was not evaluated during this study, but any decrease in cargo handling time is a gain in response time. In emergency situations, the cargo handling system weight penalty should not be an impediment, as the cargo carried would probably be less than the available aircraft payload.

8. All of the systems require ground equipment to transport cargo to the aircraft. The more highly automated systems (4, 5, and 6) require much more sophisticated equipment. Additional trained personnel are required to operate and maintain this equipment.

9. The reliability of the systems and the ease (or difficulty) with which the systems can be repaired are significant qualitative effectiveness factors, especially in the forward area in which the Army operates. The items to be considered here include:

   a. Availability of spare parts.

b. Requirements for special maintenance equipment.

c. Interchangeability of cargo handling system parts for one aircraft with those of another aircraft.

d. Whether the system is easily removable if spare parts are not available so that the aircraft is unavailable for other missions until the cargo handling system is repaired.

Systems 1 and 2 are relatively insensitive to these items. System 3 would be affected to some extent, but would be unlikely to cause an aircraft to be unavailable. System 4 would require that a mission be aborted in the event of latch failure if tiedown devices were not available. System 4 would require that an aircraft be unavailable during repair. Systems 5 and 6 would require that the aircraft be removed from service for repair, and a mission would likely be aborted if the system failed during loading.

CONCLUSIONS

The effectiveness and cost methodologies were developed specifically to evaluate the effect of automating cargo handling functions in Army aircraft. The technique was found to be applicable for the intended use and produced consistent results. While the technique is not intended for comparative evaluation of aircraft or military tactics, the data inputs, and therefore the validity of the results, are highly dependent upon the basic assumptions made in this area. These include: cargo mix, mission radius, climatic conditions, aircraft speed, threat environment, and airfield constraints. Basic to the evaluation are accurate estimates of cargo handling time and cargo handling system weight.

The functional evaluation method of determining the automation index was found to be the best method available. Application of the method requires that an analyst familiar with the cargo handling system apply the techniques in a rigorous manner. The method is limited in that the automation index must be determined for each generic cargo type.

Implicit in the application of the overall methodology is the selection of realistic cargo handling system designs.

Some Army transport aircraft will benefit from automating cargo handling. Two aircraft parameters and two mission parameters have effect on these benefits. The aircraft parameters are speed and payload. As either of these parameters is increased, the value of automating cargo handling is increased. The two mission parameters are mission range and cargo composition. As mission range decreases, the value of automating cargo handling increases. As palletized cargo becomes a larger portion of the cargo mix, the value of automating cargo handling increases. This effect of cargo mix is not critical at high values of automation index where the system handles all cargo types equally well.

There are small cost savings possible at very low ranges of automation index. The maximum effectiveness always occurs at a higher automation index than the minimum cost point.

It is significant that gains are possible when only one part of the total delivery cycle has been considered. The fact that this part of the cycle is most easily improved is also very important. While it would require extensive aircraft modification to increase aircraft speed and/or payload, an automated cargo handling system can be added to existing aircraft without major modifications.

For all aircraft studied, the addition of an automated weight and balance system results in increased effectiveness and decreased cost.

For the deployment of Army vehicles, existing Army aircraft are volume limited and the cargo handling system weight does not affect the effectiveness of the aircraft except at high automation indexes.

To provide an aircraft with the capability to airdrop supplies requires a system with a minimum automation index of 40. This permits a minimum of (1) some type of friction-reducing device on the floor of the aircraft and (2) side guidance for the cargo during airdrop.

The most significant gains from automation are realized in the performance of the airland resupply mission. The CV-2 aircraft, because of its low payload and slow speed, will not benefit from the addition of an automated cargo system. However, if the aircraft must have an aerial delivery capability, it can be provided at a small cost with only small sacrifices in effectiveness. The CV-7 aircraft will benefit from a cargo handling system with an automation index between 30 and 70. An automation index of about 40 is the minimum cost point and about 50 is the maximum effectiveness point. Between these two limits a cargo handling system can be selected based on qualitative considerations. The hypothetical 10-ton STOL will benefit from a cargo handling system with an automation index between 35 and 90. An automation index of about 40 is the minimum cost point and about 60 is the maximum effectiveness point. Between these two limits a cargo handling system can be selected based on qualitative factors.

The CH-47 will benefit from a cargo handling system with an automation index between 35 and 90. An automation index of about 35 is the minimum cost point and 40 to 90 is the maximum effectiveness range. Between these two limits a cargo handling system can be selected based on qualitative factors.

The results of the analysis are conservative for two reasons. First, in all cases, aircraft were assumed to carry full payload (with the exception of space limited vehicle loads). Operationally it is the objective of loading crews to gross out every aircraft; but, due to the heterogeneous nature of cargo, this is not always possible. Second, for the CH-47 operating in an area of enemy fire, the vulnerability per exposure remained constant regardless of the time of exposure.

RECOMMENDATIONS

Based on the results of the study it is recommended that all future (and present if possible) Army transport aircraft be equipped with an automatic weight and balance system.

There are several areas in which additional work would appear to be justified:

1. Apply the methodology to a VTOL-type aircraft.

2. Investigate helicopters in a forward area environment to establish the value of decreased cargo handling time.

3. Establish the interface between ground and air vehicles and determine the impact on system effectiveness and cost.

4. Perform an in-depth evaluation of retrograde cargo, including makeup of the cargo and special handling requirements.

5. Examine the impact of emergency delivery (as opposed to routine resupply) requirements on system effectiveness and cost.

6. Perform a design analysis to select a standard cargo handling system with an automation index in the 30 to 70 range to be easily adaptable to all Army transport aircraft.

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GLOSSARY
(As Used in the Context of This Report)

Aircraft	The aircraft proper, exclusive of cargo handling systems.
Automation	The reduction of human energy input or human decision in a cargo handling operation or task by the addition of equipment to an aircraft.
Automation Index	A whole number indicating the degree of automation of a particular cargo handling system in handling one type of cargo, ranging from 0 to 132.
Availability	Percent of total aircraft on hand which are capable of performing their primary mission.
Average Operating Aircraft	The average number of aircraft performing throughout a mission; determined by deducting half the combat losses from the total aircraft on hand at the start of the mission. This quantity is only valid in dealing with one specific cargo load.
Cargo	General term applicable to any payload carried by an aircraft.
Cargo Handling System	Any system in an Army aircraft capable of handling all types of cargo.
Composite Automation Index	A number indicating the degree of automation of a particular cargo handling system in handling the total cargo quantity; obtained by weighting the automation index for each type of cargo by the percent of the total cargo quantity which is that type of cargo and by weighting the automation index for each mixed load in the total cargo quantity by the percent of the total cargo quantity which is that mixed load, then summing the weighted values.
Cycle	One primary flight plus one retrograde flight of one aircraft, including ground time.
Delivery System	An aircraft/cargo handling system combination.

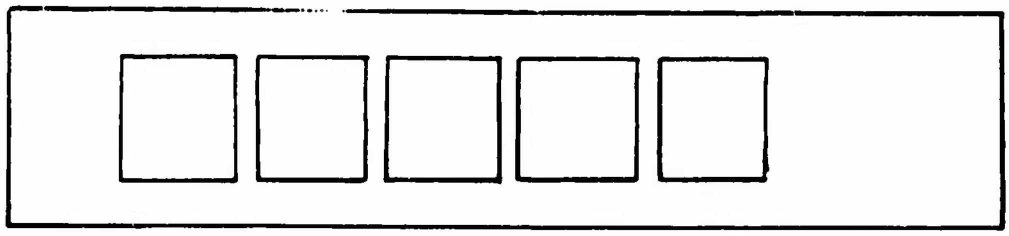
Delivery System Investment Cost	The total first cost of the aircraft and automated cargo handling system. Defined to consist of the flyaway cost and initial support cost of the aircraft plus the research and development, flyaway cost, and initial support cost of the cargo handling system.
Flyaway Cost	The basic unit cost of the system or subsystem less any RDT&E and/or initial support costs.
Function	As pertains to this study, a function is an action performed by a person and/or piece of hardware in the cargo handling process.
Initial Support Cost	The initial cost of introducing a system or subsystem into the operational inventory, in addition to RDT&E and flyaway costs.
Mission	Delivering a fixed quantity of cargo a fixed distance (specified by radius), given the delivery mode, aircraft vulnerability, and specified time period in which the deliveries must be made.
Mixed Load	Mixed aircraft load containing more than one type of cargo.
Mixed Load Automation Index	A number indicating the degree of automation of a particular cargo handling system in handling one specific mixed load; obtained by weighting the automation index for each type of cargo contained in the mixed load by the percent of the mixed load which is that type of cargo, then summing the weighted values.
Operating Day	The continuous segment of a 24-hour day during which the assigned mission is performed.
Primary Flight	Flight by a single aircraft carrying full payload from either a logistic support base or an interphase terminal toward the forward area, including both ground time and flying time.
Rating	A value indicative of the amount of automation inherent in the performance of a single function by a particular cargo handling system.
Research and Development Cost	The total resources (in dollars) required to bring a system (or subsystem) into production status.

Retrograde Flight	Flight by a single aircraft carrying a partial payload (casualties, prisoners, human remains, collapsible fabric fuel containers, or other cargo) from either the forward area or interphase terminal toward the logistic support base, including both ground time and flying time.
Total Aircraft Required	The total number of aircraft required at the start of a mission, determined by the average number required to perform the mission and the number lost during the mission.
Total Cargo Quantity	Total quantity of cargo to be delivered on a mission.
Total Mission Cost	For each mission requirement, the sum (in dollars) of the total mission investment cost, the total mission operating cost, and the total mission loss cost.
Total Mission Flying Hours	The total flying time expended by the required number of delivery systems in performing the assigned mission.
Total Mission Ground Hours	The total ground time required by the delivery systems in performing the assigned mission.
Total Mission Investment Cost	The product of the total operating days required per mission, the average number of aircraft required per mission, and the investment cost per delivery system per operating day.
Total Mission Operating Cost	The sum total of four cost-rate functions based on operating cost per operating day, operating cost per ton loaded, operating cost per flight hour, and operating cost per ground hour.
Total Mission Loss Cost	Replacement cost of downed aircraft which cannot be repaired.
Total Time	A continuous time period during which the delivery of the total quantity of cargo must be completed.
Type Cargo	Cargo of one type, that type being either pallets, bulk, vehicles, or nonpalletized POL.
Type Load	Specific aircraft load having a specified cargo quantity and composition.

APPENDIX

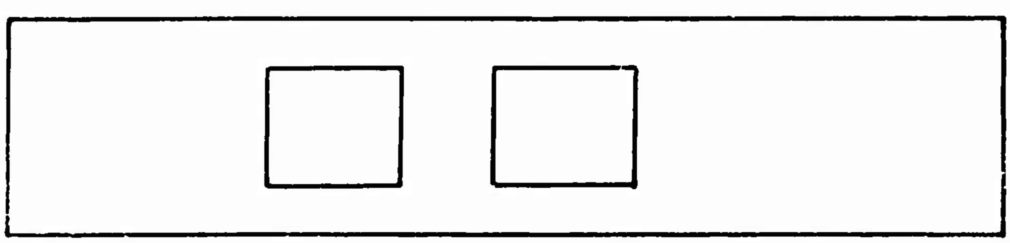
CARGO LOADS AND HANDLING TIMES

CV-2 Load 1 1500-lb Pallets



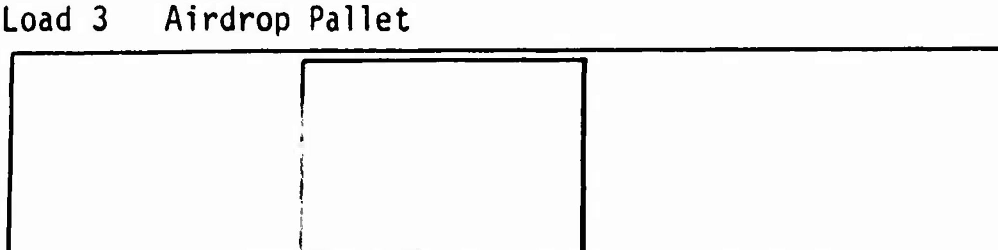
CHS	1	2	3	4	5	6
Load Time (min)	13.75	25.50	6.50	3.00	2.50	2.40
Unload Time (min)	10.5	21.65	4.00	3.00	2.50	2.40
Payload (tons)	3.53	3.58	3.40	3.22	3.01	2.71

CV-2 Load 2 3500-lb Pallets (Palletized POL)



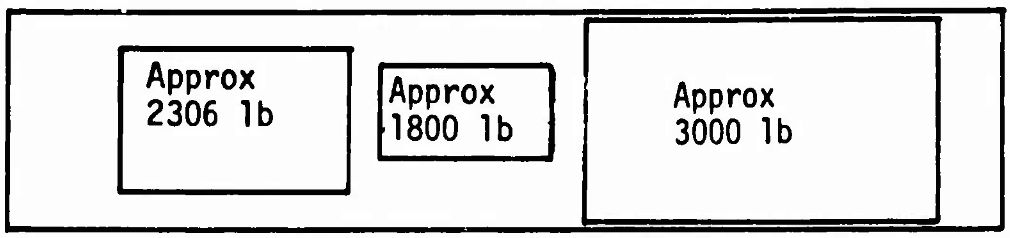
CHS	1	2	3	4	5	6
Load Time (min)	6.25	11.50	6.00	3.00	1.50	2.00
Unload Time (min)	6.10	10.20	4.00	3.00	1.50	2.00
Payload (tons) Pallets	3.53	3.58	3.40	3.22	3.01	2.71
Payload (tons) POL	3.43	3.43	3.30	3.32	3.11	2.71

CV-2 Load 3 Airdrop Pallet



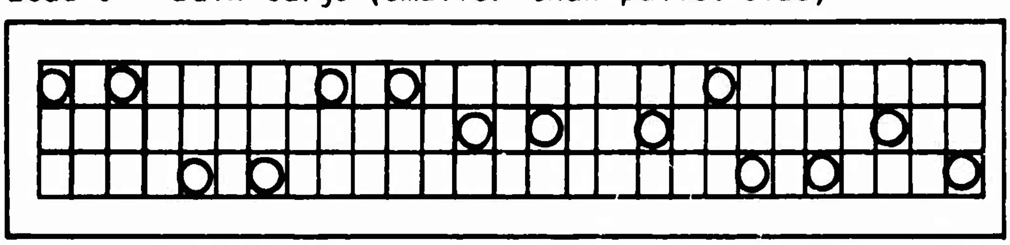
CHS	3	4	5
Load Time (min)	10.00	3.00	2.00
Unload Time (min)	0.20	0.20	0.20
Payload (tons)	3.03	3.06	2.82

CV-2 Load 4 Bulk Cargo (Greater than pallet size)



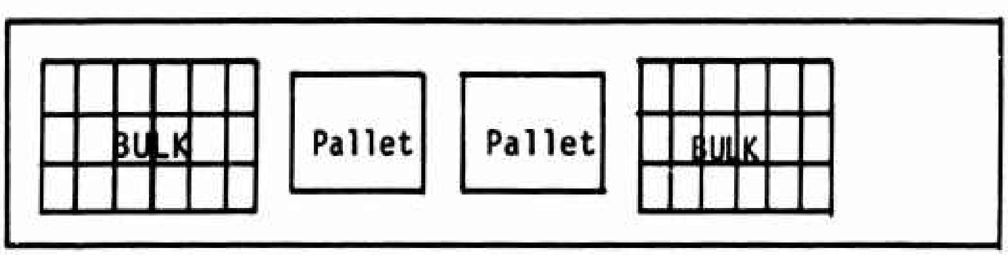
CHS	1	2	3	4	5	6
Load Time (min)	13.00	13.00	13.00	13.00	13.00	5.00
Unload Time (min)	7.00	7.00	7.00	7.00	7.00	3.00
Payload (tons)	3.53	3.58	3.40	3.42	3.21	2.71

CV-2 Load 5 Bulk Cargo (Smaller than pallet size)



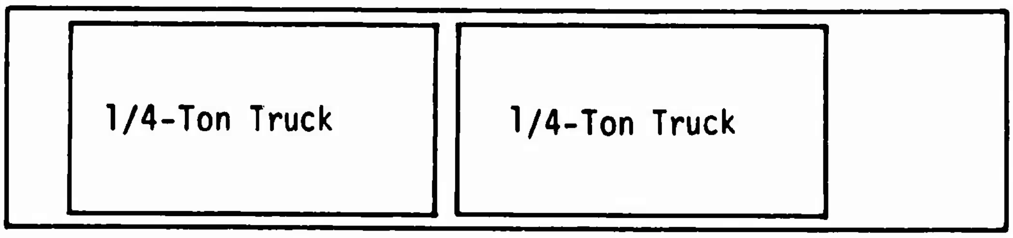
CHS	1	2	3	4	5	6
Load Time (min)	36.00	35.55	31.46	34.15	32.35	7.00
Unload Time (min)	34.00	33.55	29.70	32.24	30.55	6.00
Payload (tons)	3.43	3.58	3.30	3.42	3.21	2.71

CV-2 Load 8 Mixed Cargo



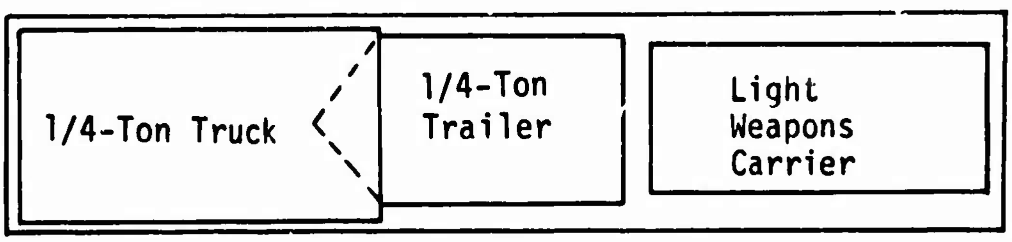
CHS	1	2	3	4	5	6
Load Time (min)	31.00	33.50	27.00	31.00	31.00	4.00
Unload Time (min)	29.00	33.00	23.00	29.00	29.00	2.00
Payload (tons)	3.53	3.58	3.40	3.42	3.21	2.71

CV-2 Load 11 Two 1/4-Ton Trucks



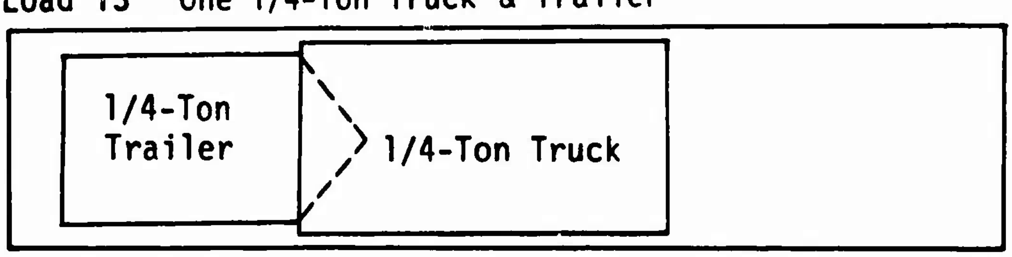
CHS	1	2	3	4	5	6
Load Time (min)	6.00	6.00	6.00	6.00	3.50	5.00
Unload Time (min)	2.25	2.25	2.25	2.25	2.00	2.25
Payload (tons)	3.07	3.07	3.07	3.07	3.07	2.71

CV-2 Load 12 One 1/4-Ton Truck & Trailer & One Light Weapons Carrier



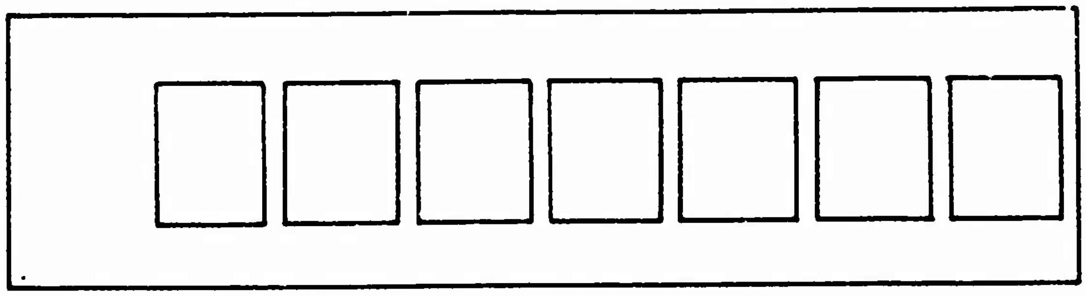
CHS	1	2	3	4	5	6
Load Time (min)	6.00	6.00	6.00	6.00	3.75	4.50
Unload Time (min)	3.25	3.25	3.25	3.25	3.00	2.50
Payload (tons)	3.05	3.05	3.05	3.05	3.05	2.71

CV-2 Load 13 One 1/4-Ton Truck & Trailer



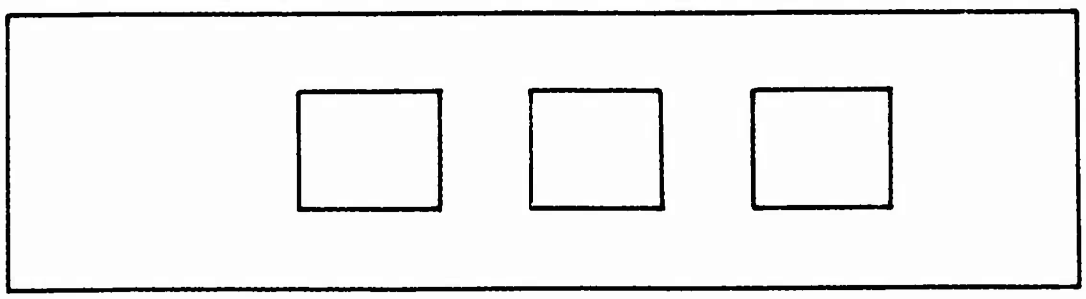
CHS	1	2	3	4	5	6
Load Time (min)	8.00	8.00	8.00	8.00	3.25	4.00
Unload Time (min)	2.00	2.00	2.00	2.00	1.50	2.00
Payload (tons)	2.07	2.07	2.07	2.07	2.07	2.07

CV-7 Load 1 1500-lb Pallets



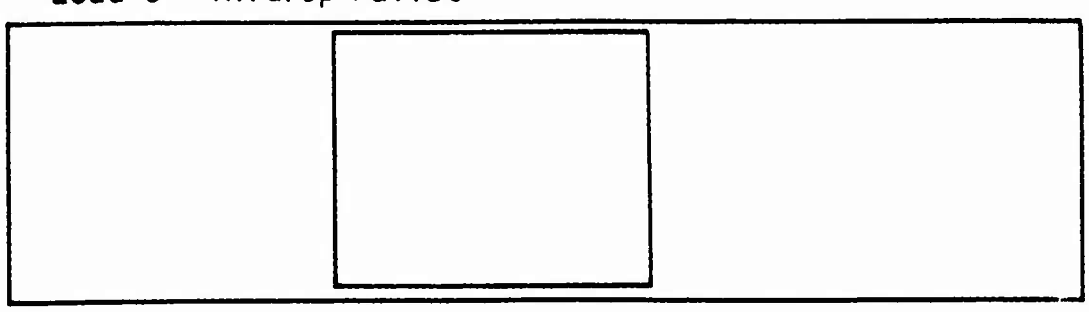
CHS	1	2	3	4	5	6
Load Time (min)	17.50	28.00	7.00	5.50	2.50	2.50
Unload Time (min)	12.50	25.00	6.50	3.50	2.50	2.50
Payload (tons)	5.09	5.23	4.91	4.67	4.26	4.11

CV-7 Load 2 3500-lb Pallets



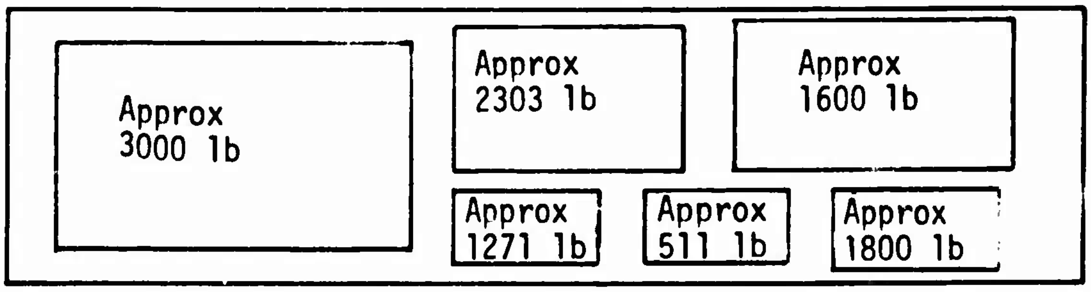
CHS	1	2	3	4	5	6
Load Time (min)	11.50	15.50	6.00	5.00	2.50	2.50
Unload Time (min)	9.50	14.00	6.00	4.50	2.00	2.50
Payload (tons)	5.09	5.23	4.91	4.85	4.44	4.11

CV-7 Load 3 Airdrop Pallet



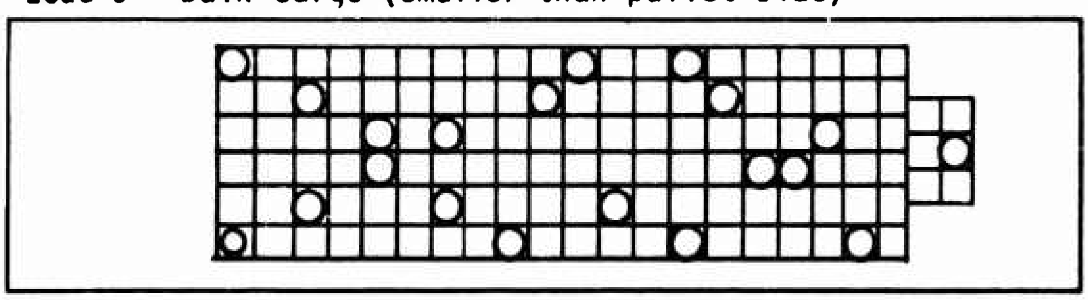
CHS	3	4	5
Load Time (min)	10.00	3.00	2.00
Unload Time (min)	0.20	0.20	0.20
Payload (tons)	3.38	3.38	3.38

CV-7 Load 4 Bulk Cargo (Greater than pallet size)



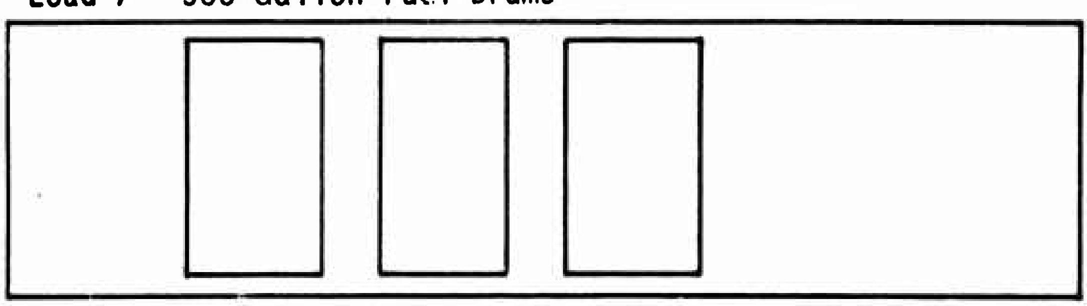
CHS	1	2	3	4	5	6
Load Time (min)	22.00	22.00	22.00	22.00	22.00	5.00
Unload Time (min)	12.00	12.00	12.00	12.00	12.00	4.00
Payload (tons)	5.09	5.23	4.91	5.04	4.62	4.11

CV-7 Load 5 Bulk Cargo (Smaller than pallet size)



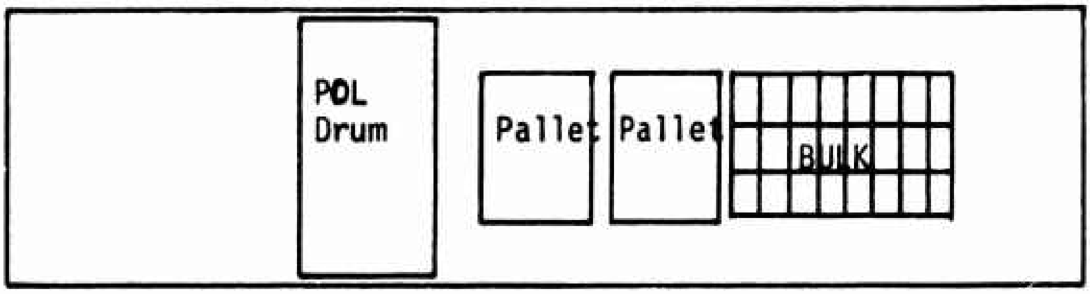
CHS	1	2	3	4	5	6
Load Time (min)	34.00	34.35	31.45	33.32	28.90	7.00
Unload Time (min)	30.00	30.45	27.67	29.45	26.05	6.00
Payload (tons)	5.09	5.23	4.91	5.04	4.62	4.11

CV-7 Load 7 500-Gallon Fuel Drums



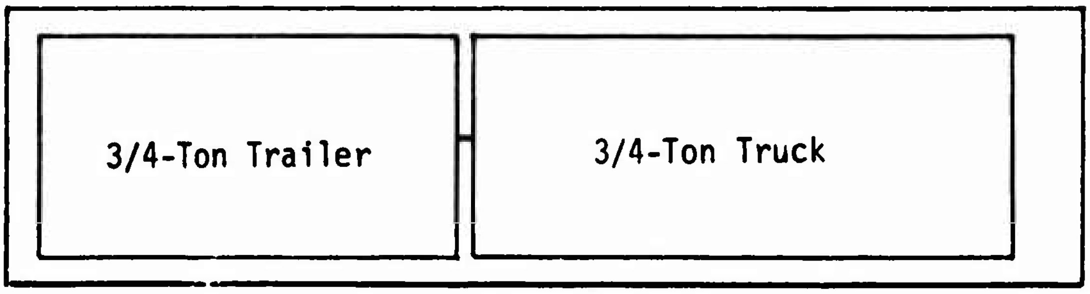
CHS	1	2	3	4	5	6
Load Time (min)	25.00	12.75	12.75	12.75	9.50	7.50
Unload Time (min)	25.00	11.75	11.75	11.75	8.50	6.75
Payload (tons)	5.09	5.23	4.91	5.04	4.62	4.11

CV-7 Load 8 Mixed Cargo



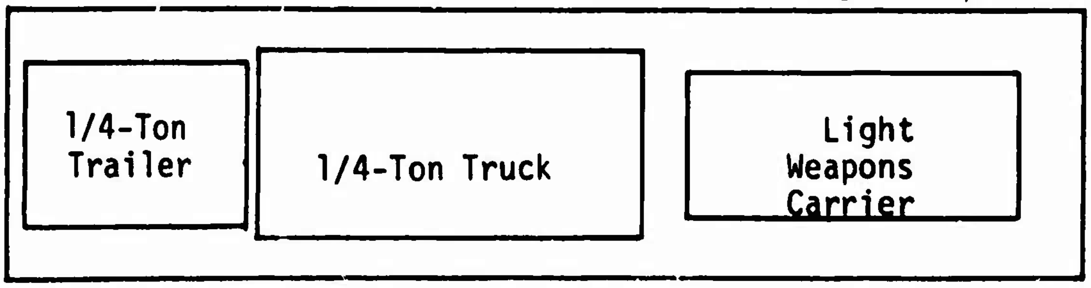
CHS	1	2	3	4	5	6
Load Time (min)	27.00	27.00	23.00	27.00	27.00	3.50
Unload Time (min)	24.00	24.00	20.00	23.00	23.00	2.50
Payload (tons)	5.09	5.23	4.91	5.04	4.62	4.11

CV-7 Load 14 One 3/4-Ton Truck & Trailer



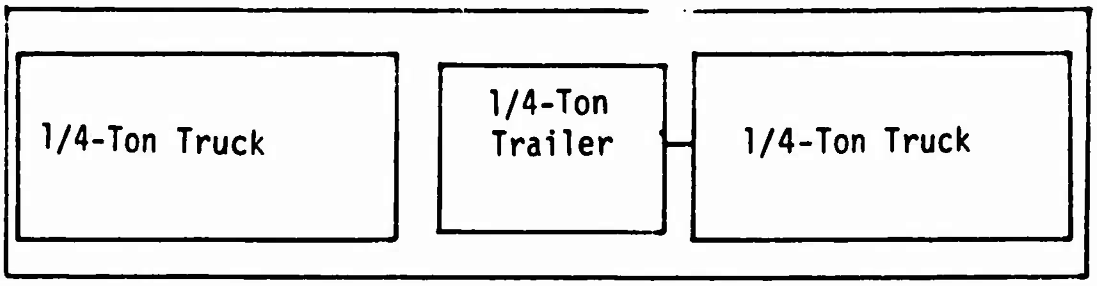
CHS	1	2	3	4	5	6
Load Time (min)	9.00	9.00	9.00	9.00	3.75	4.00
Unload Time (min)	2.50	2.50	2.50	2.50	1.50	2.00
Payload (tons)	5.09	5.23	4.91	5.04	4.62	4.11

CV-7 Load 15 One 1/4-Ton Truck & Trailer & One Light Weapons Carrier



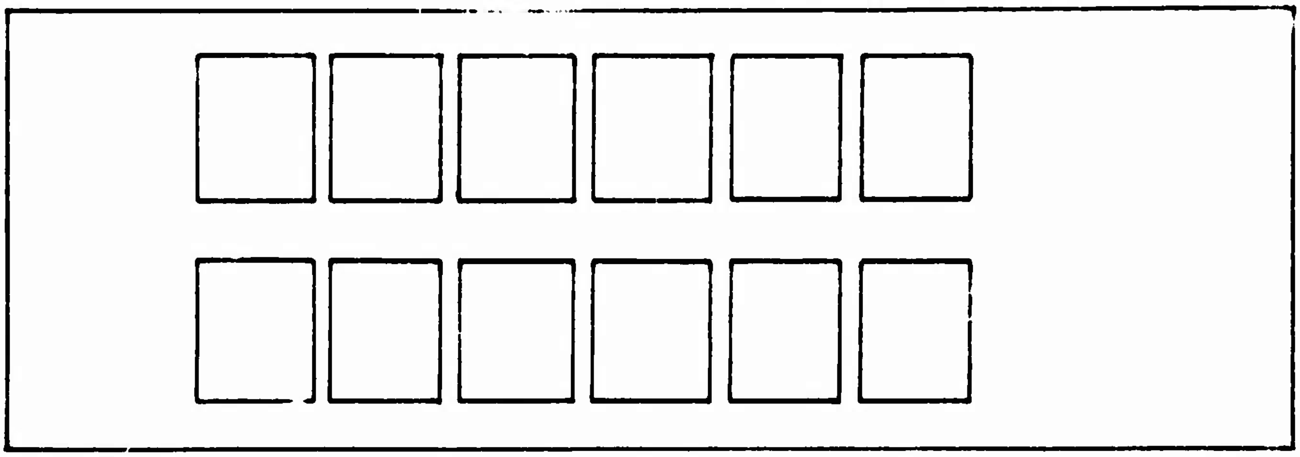
CHS	1	2	3	4	5	6
Load Time (min)	8.00	8.00	8.00	8.00	3.75	4.50
Unload Time (min)	1.75	1.75	1.75	1.75	2.00	2.50
Payload (tons)	3.05	3.05	3.05	3.05	3.05	3.05

CV-7 Load 16 One 1/4-Ton Truck & Trailer & One 1/4-Ton Truck



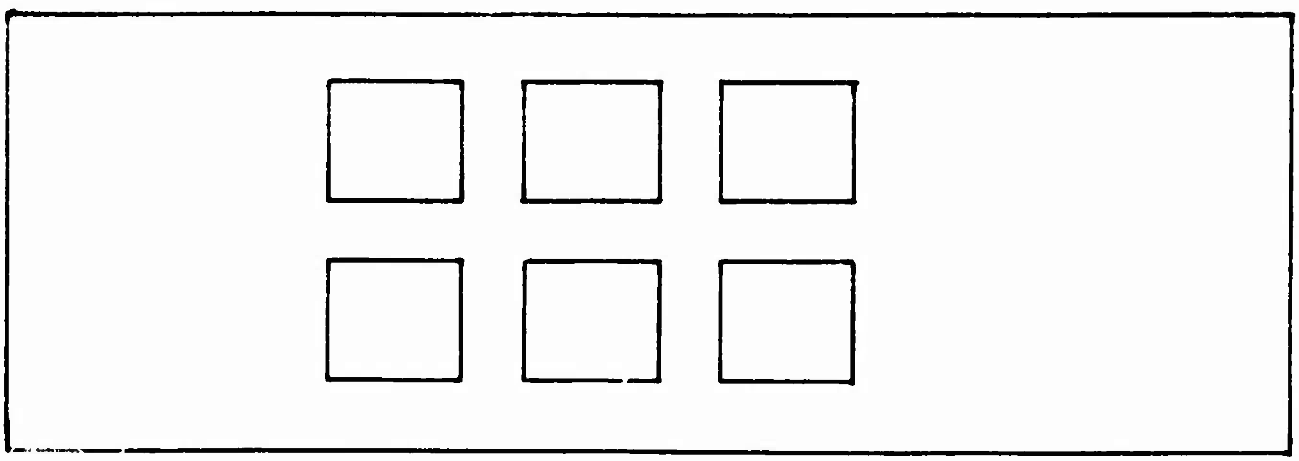
CHS	1	2	3	4	5	6
Load Time (min)	8.00	8.00	8.00	8.00	4.00	4.50
Unload Time (min)	2.25	2.25	2.25	2.25	2.00	2.50
Payload (tons)	3.60	3.60	3.60	3.60	3.60	3.60

10-Ton STOL Load 1 1500-lb Pallets



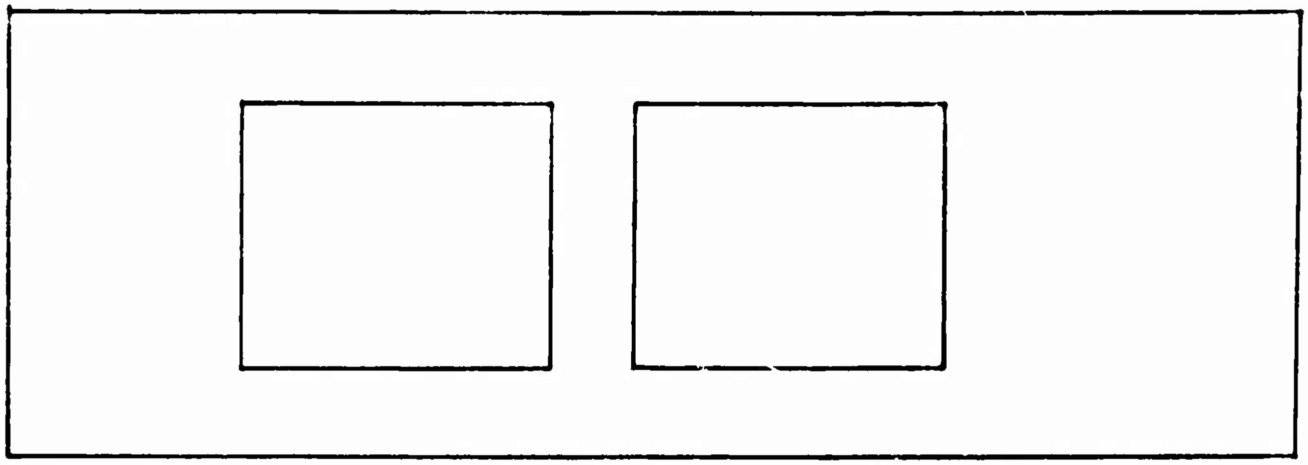
CHS	1	2	3	4	5	6
Load Time (min)	17.50	37.50	9.35	4.50	4.00	4.00
Unload Time (min)	16.00	31.00	8.50	4.00	4.00	4.00
Payload (tons)	9.74	9.90	9.54	9.20	8.54	8.57

10-Ton STOL Load 2 3500-lb Pallets



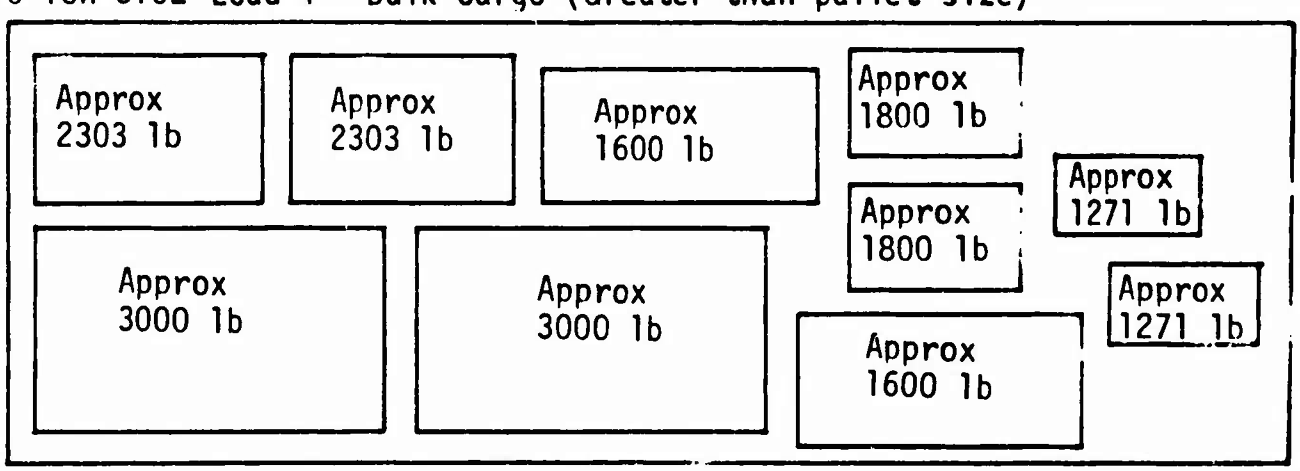
CHS	1	2	3	4	5	6
Load Time (min)	11.50	19.25	7.50	4.50	4.00	4.00
Unload Time (min)	9.50	18.00	6.70	4.00	4.00	4.00
Payload (tons)	9.74	9.90	9.54	9.38	8.73	8.57

10-Ton STOL Load 3 Airdrop Pallets



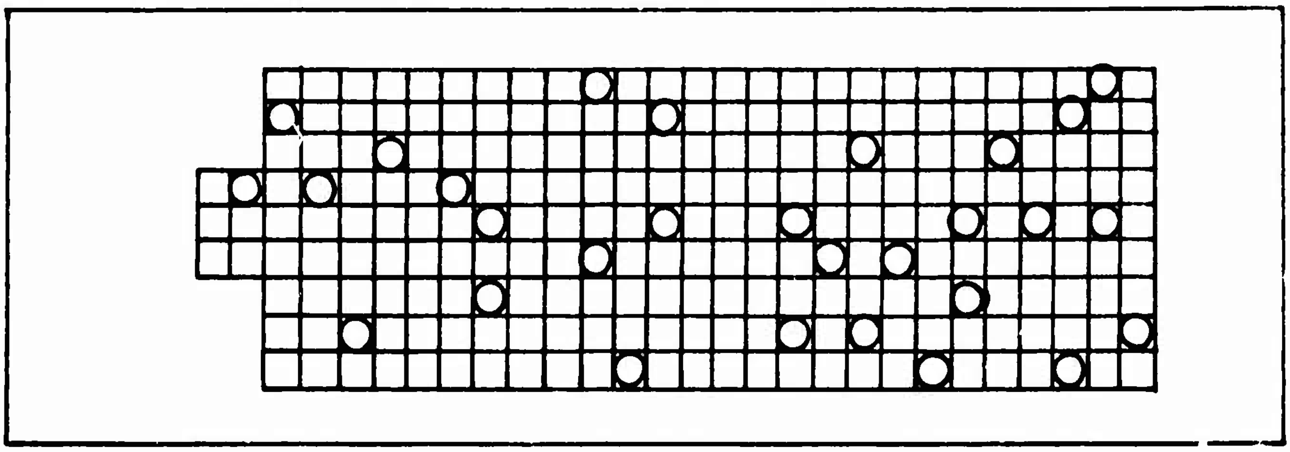
CHS	3	4	5
Load Time (min)	14.50	3.50	2.50
Unload Time (min)	0.30	0.30	0.30
Payload (tons)	8.76	8.96	8.31

10-Ton STOL Load 4 Bulk Cargo (Greater than pallet size)



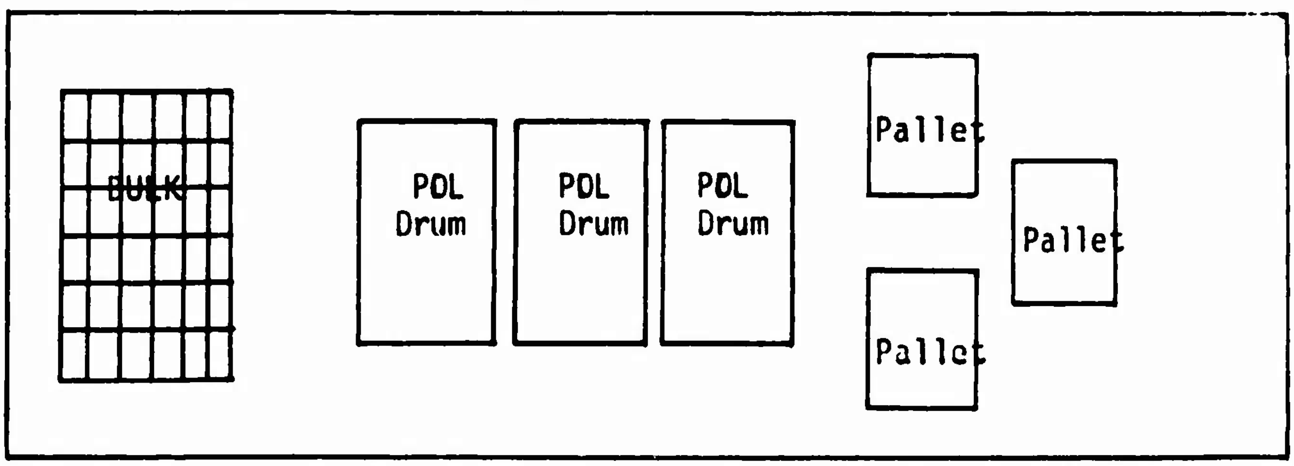
CHS	1	2	3	4	5	6
Load Time (min)	35.00	37.00	37.00	37.00	37.00	6.00
Unload Time (min)	25.00	28.00	28.00	28.00	28.00	5.00
Payload (tons)	9.74	9.90	9.54	9.74	9.09	8.57

10-Ton STOL Load 5 Bulk Cargo (Smaller than pallet size)



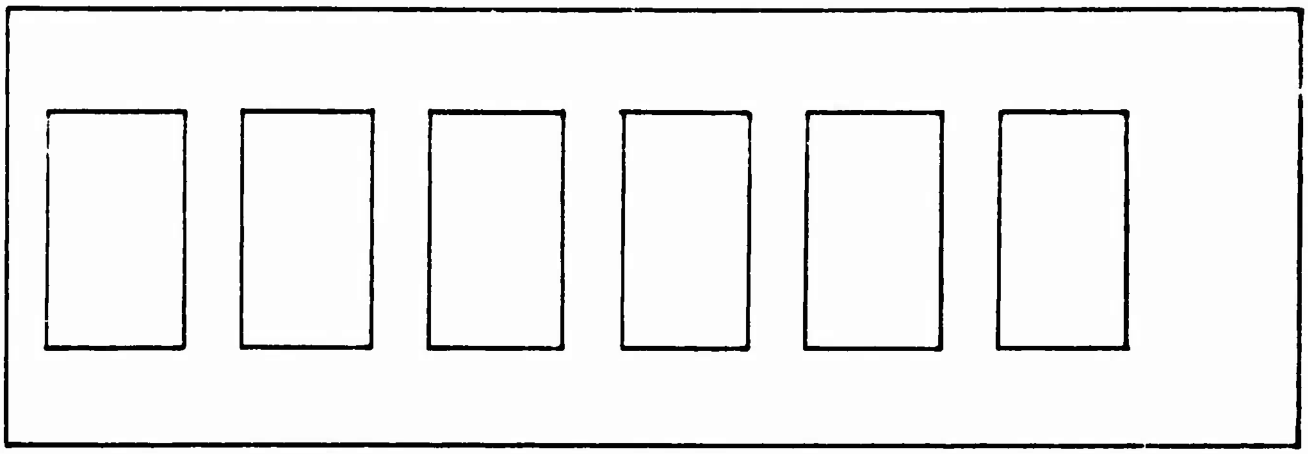
CHS	1	2	3	4	5	6
Load Time (min)	50.00	50.60	47.28	49.75	46.26	6.00
Unload Time (min)	48.00	48.60	45.37	47.75	44.40	5.00
Payload (tons)	9.74	9.90	9.54	9.74	9.09	8.57

10-Ton STOL Load 6 Mixed Cargo



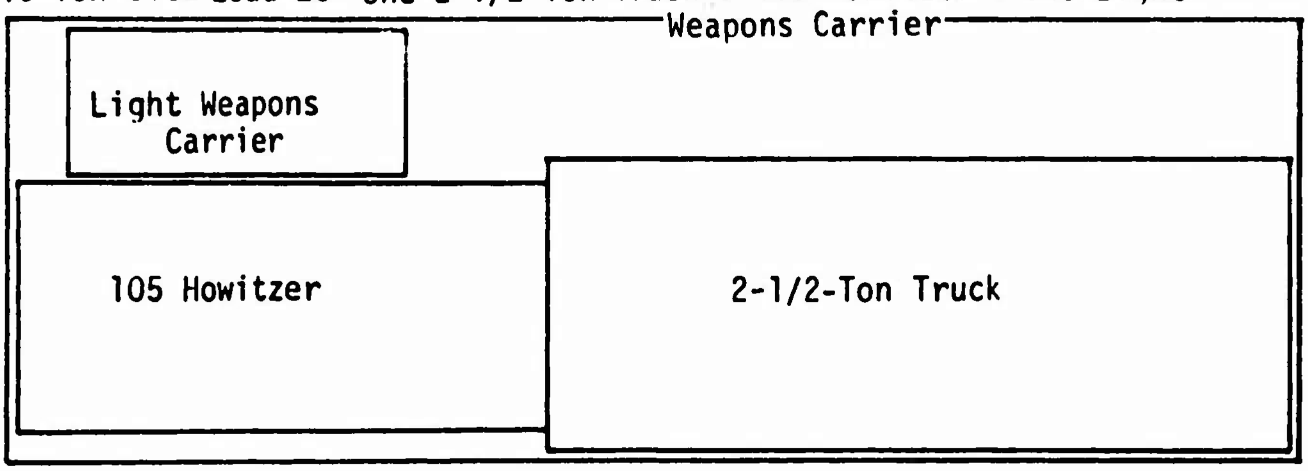
CHS	1	2	3	4	5	6
Load Time (min)	33.00	33.00	28.00	33.00	33.00	5.00
Unload Time (min)	30.00	30.00	26.00	30.00	30.00	3.00
Payload (tons)	9.74	9.90	9.54	9.74	9.09	8.57

10-Ton STOL Load 7   500-Gallon Fuel Drums



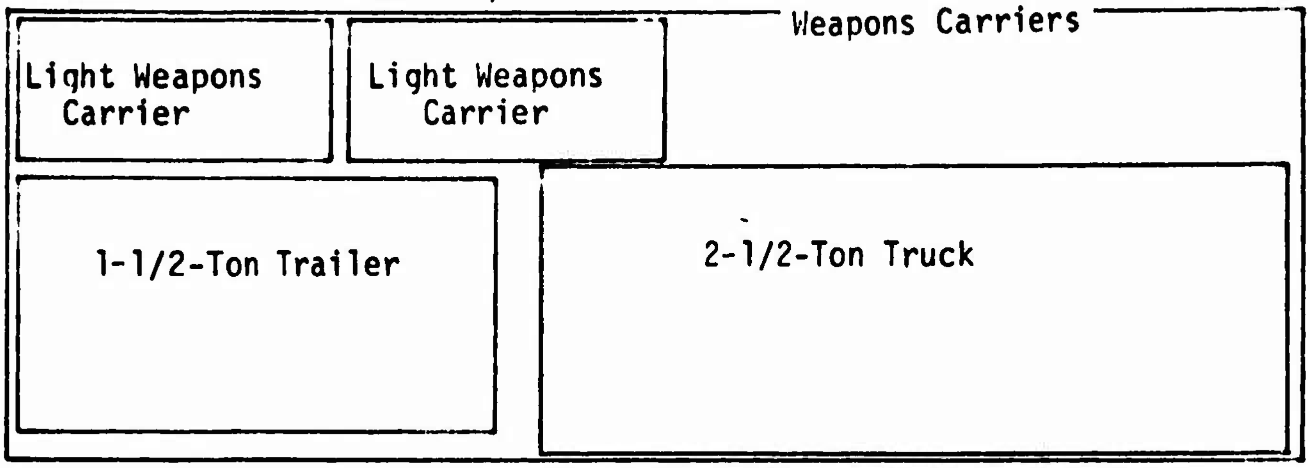
CHS	1	2	3	4	5	6
Load Time (min)	38.00	24.50	24.50	24.50	17.00	10.00
Unload Time (min)	38.00	20.25	20.25	20.25	16.00	9.25
Payload (tons)	9.74	9.90	9.54	9.74	9.09	8.57

10-Ton STOL Load 20 One 2-1/2-Ton Truck & 105 Howitzer & One Light Weapons Carrier



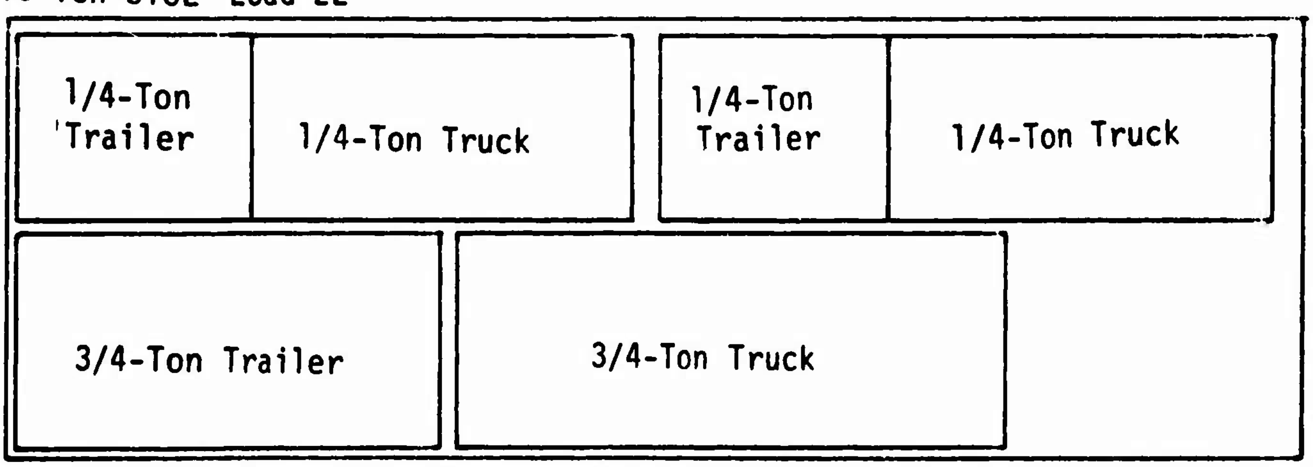
CHS	1	2	3	4	5	6
Load Time (min)	16.00	16.00	16.00	16.00	8.00	7.00
Unload Time (min)	3.00	3.00	3.00	3.00	1.75	2.25
Payload (tons)	9.74	9.90	9.54	9.74	9.09	8.57

10-Ton STOL Load 21 One 2-1/2-Ton Truck & One 1-1/2-Ton Trailer & Two Light Weapons Carriers



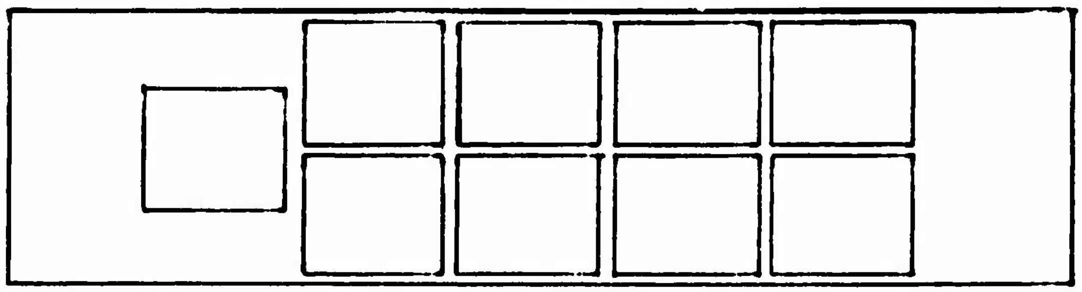
CHS	1	2	3	4	5	6
Load Time (min)	16.00	16.00	16.00	16.00	8.00	12.00
Unload Time (min)	3.00	3.00	3.00	3.00	1.75	2.25
Payload (tons)	9.74	9.90	9.54	9.74	9.09	8.57

10-Ton STOL Load 22



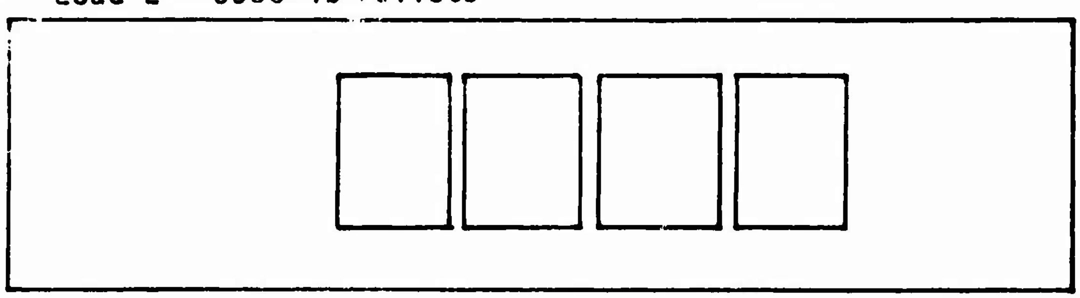
CHS	1	2	3	4	5	6
Load Time (min)	12.00	12.00	12.00	12.00	10.00	11.00
Unload Time (min)	3.00	3.00	3.00	3.00	2.50	2.00
Payload (tons)	9.74	9.90	9.54	9.74	9.09	8.57

CH-47 Load 1 1500-lb Pallets



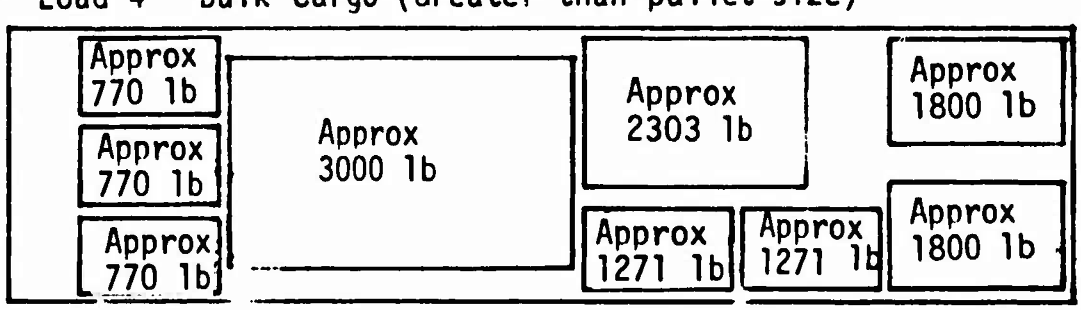
CHS	1	2	3	4	5	6
Load Time (min)	20.50	29.50	8.50	6.00	3.50	2.50
Unload Time (min)	14.50	28.00	7.50	4.00	2.50	2.50
Payload (tons)	6.79	6.93	6.60	6.19	5.78	5.80

CH-47 Load 2 3500-lb Pallets



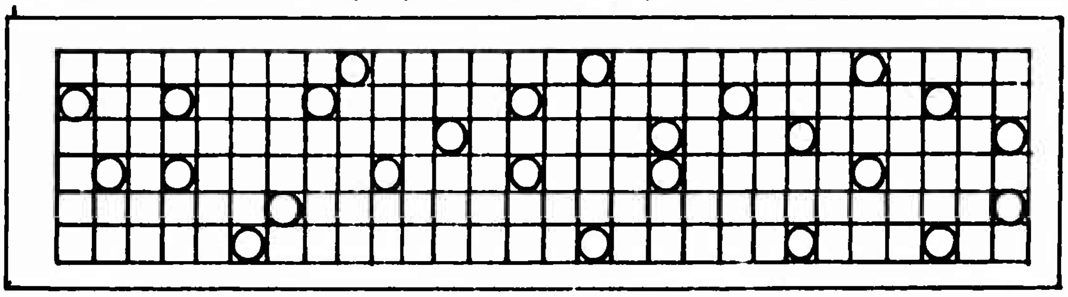
CHS	1	2	3	4	5	6
Load Time (min)	14.00	18.00	7.50	5.50	2.50	2.50
Unload Time (min)	11.00	17.00	6.50	5.00	2.00	2.50
Payload (tons)	6.79	6.93	6.60	6.36	5.97	5.80

CH-47 Load 4 Bulk Cargo (Greater than pallet size)



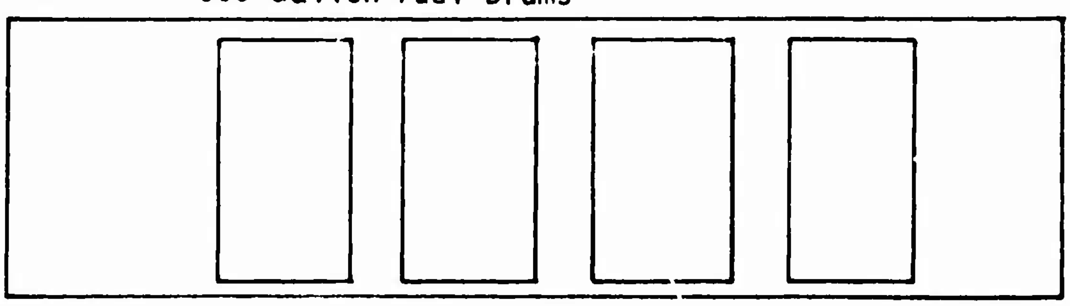
IS	1	2	3	4	5	6
Load Time (min)	26.00	26.00	26.00	26.00	26.00	7.00
Unload Time (min)	15.00	15.00	15.00	15.00	15.00	5.00
Payload (tons)	6.79	6.93	6.60	6.74	6.33	5.80

CH-47 Load 5 Bulk Cargo (Smaller than pallet size)



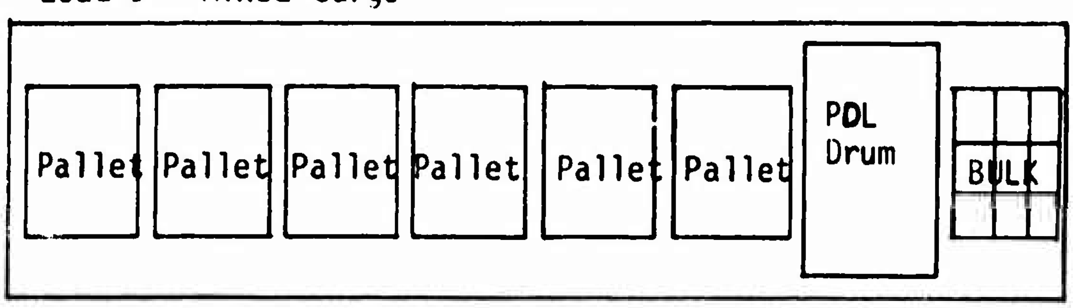
CHS	1	2	3	4	5	6
Load Time (min)	45.30	45.65	42.70	44.50	41.90	9.00
Unload Time (min)	38.80	39.30	36.80	37.30	35.90	8.00
Payload (tons)	6.79	6.93	6.60	6.74	6.33	5.80

CH-47 Load 7 500-Gallon Fuel Drums



CHS	1	2	3	4	5	6
Load Time (min)	32.40	16.00	16.00	16.00	12.00	6.50
Unload Time (min)	32.40	15.25	15.25	15.25	12.00	5.00
Payload (tons)	6.79	6.93	6.60	6.74	6.33	5.80

CH-47 Load 9 Mixed Cargo



CHS	1	2	3	4	5	6
Load Time (min)	27.00	27.00	23.00	27.00	27.00	4.50
Unload Time (min)	24.00	24.00	20.00	24.00	24.00	2.50
Payload (tons)	6.79	6.93	6.60	6.74	6.33	5.80

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Donald A. Andrastek
Reginald R. Belding
James W. Wollaston

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13. ABSTRACT

In the first phase of the two-phase study, methodologies were developed to (1) measure the degree of automation of a given cargo handling system and (2) evaluate the gains and penalties resulting from automating cargo handling functions in Army aircraft from a cost/effectiveness point of view. Basic to the study were the effects of cargo handling equipment in Army aircraft on aircraft payload, cargo handling time, manning, aircraft availability, aircraft vulnerability and costs.

Several cargo handling systems were evaluated in the second phase of the study. These systems ranged from manual to very highly automated and were evaluated in the CV-2, CV-7, CH-47, and a hypothetical 10-ton STOL. Elements not affected by the cargo handling system were held constant whenever possible.

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Automation						
Cargo						
Cargo Handling System						
Cost/Effectiveness						